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ON HAIL

ON HAIL

BY

Francis Albert

THE HON. ROLLO RUSSELL, F.R. MET. SOC.

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AT WHOSE SUGGESTION

THE WORK WAS UNDERTAKEN, AND WHO

KINDLY SUPPLIED MUCH OF THE MATERIAL ON WHICH

IT IS BASED,

this book is respectfully dedicated.

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ON HAIL.

CHAPTER I.

DESCRIPTIONS OF HAILSTORMS AND HAILSTONES.

THE following descriptions are mostly taken from witnesses upon whom reliance can be placed, and although not so full and detailed as might be wished, they give a fair idea of the character of some of the phenomena by which the greatest hailstorms are distinguished.

1. ACCOUNT OF THE GREAT HAILSTONES THAT FELL IN LONDON ON MAY 18, 1680.*

Dr. Hook relates that—"On May 17 it rained almost all day, that at about 3 or 4 A.M. there was very much thunder and lightning, and an exceedingly violent shower of rain. Rain and occasional thunder continued until about 9 A.M., then the sun shone, and scarce a cloud was to be seen; about 10 it began to thicken, and about

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* Hook's 'Philosophical Experiments.'

10.30 it grew very dark and thundered very near." Soon after this there began to fall "a good quantity of hailstones, some of the bigness of pistol-bullets, others as big as pullets' eggs, and some above 2½ inches, and near 3 inches over the broad way; the smaller were pretty round, and white, like chalk or sugar-plums; the others of other shapes; some of the most remarkable were these:" (diagrams given). "Breaking many of them, I found them to be made up of orbs of ice, one encompassing another, some of them transparent, and some white and opaque. . . . Some of them had the white spot in the middle, at A; others towards one side, at B; and the variety of white and transparent spots very differing; those which exceeded these in bigness, were made by an additional accretion of transparent icicles, radiating every way from the surface of the white ball, like the shooting of niter, or toothed sparre. These in some stood as it were separate in distinct icicles, which were very clear and transparent, and had a bleb or whiteness in them.

"Others of them were all concreted into a solid lump, and the interstices filled up with ice, which was not so clear as the striæ, but whiter; and thereby one side, which I suppose was the undermost, was flat, almost like a turnep; and the radiations appeared to proceed from the ball in the middle, more towards the upper side and most towards the sides; the edges and top were more rough, and the ends of the striæ appeared prominent, which the figures will better express."

2. Accounts of Hailstorms from Howard's 'Climate of London.'

On the night of Friday, the 15th July, 1808, after several days of uncommon and oppressive heat, the city of Gloucester experienced a storm of thunder and lightning, which extended many miles round, and exceeded in awful phenomena any one remembered for many years past. Unlike the tempest of the milder zones, the thunder was remarked to roll in one continued roar for upwards of an hour and a half, during which time, and long afterwards, the flashes of lightning followed each other in rapid and uninterrupted succession. But the most tremendous circumstance of this storm was the destructive *hail shower* which accompanied its progress. It may be doubted, however, whether such a name be applicable; for the masses of ice which fell on the places where the tempest most fiercely raged, bore no resemblance to hailstones in magnitude or formation, most of them being of a very irregular shape, broad, flat, and ragged, and many measuring from 3 to 9 inches in circumference. They appeared like fragments of a vast plate of ice, broken into small masses in its descent towards the earth. The storm rose in the south-west, and spreading to the north-west, gradually died away in the north-east, from which quarter it was opposed for nearly its whole duration by a strong breeze, particularly hollow and mournful in its sound. The damage done in different parts of this and other counties was very considerable.

Sussex, March 28, 1809.—Between one and two o'clock the town of Horsham was visited by a storm (of thunder and hail); the tempest appeared to run in a south-west direction with a thick and gloomy atmosphere, and after many awful flashes of lightning and tremendous explosions, produced *hail* with a degree of violence that dealt destruction to the windows, &c. (The damage done to *gardens* more especially is here noted.) The hailstones were from 2 to 3 inches in circumference, and from their uneven formation appeared like rugged pieces of ice, covering the streets nearly shoe deep. The storm, though so heavy, was limited chiefly to the town.

Account of the Hailstorm on May 19, 1809.—The day had been sultry, like some preceding ones, and overcast with clouds, which during the afternoon gave evident demonstrations of an approaching discharge of electricity. Large and deep cumulostrati were ranged side by side, mingled with the Cirrocumulus and Cirrostratus, the whole having that peculiar, almost indescribable character, which these charged conductors assume, when wrought up to the highest state of electric *tension*. About five in the afternoon, being at the laboratory, and perceiving a continued roll of thunder, with vivid lightning approaching from the south, and the appearance of a heavy shower in that quarter, I anticipated a storm of no common violence. We were proceeding to take measures for the safety of some glass utensils, when, in an instant, there opened upon us a volley of hail of such tremendous force, as in ten, or at most fifteen minutes, demolished most part of the skylights and south windows in the neighbourhood.

These *icy bullets*, some of them a full inch in diameter, were discharged almost horizontally from a cloud to the windward, and in such quantity as to be drifted in large masses under the wall. Whether borne by the impetuous blast that came with them, or carrying the air thus before them, I could not determine, but such was the velocity of their motion that in many instances a clear round hole was left in the glass they pierced; and one large pane (which I saw) had *two* such perforations distinctly formed, the glass otherwise whole. The water in the river, lashed by the hail and raised by the wind, resembled a cauldron boiling violently, rather than waves with breakers.

The electrical discharges were incessant, approaching with the cloud, and passing off with it; so that the whole resembled, in effect, the more mischievous artillery of human invention; inspiring, in spite of philosophic reflection and delight at the grand and unusual phenomena, a sense of actual danger.

This sudden irruption over, it rained for a while moderately. The wind was at first east, then south during the hail, then west, then east, then west again.

About seven, the clouds all at once put off their stormy character, and appeared as if going to sleep after this prodigious expenditure of power. The remainder of the evening was calm and pleasant.

Remarkable Hailstorm in Bedfordshire, October 19, 1800.—The following particulars of a destructive hailstorm in Bedfordshire, were communicated to me by my friend and relation, Richard Howe, of Aspley, who showed me the scars then remaining in the stems of fir trees in his plantation, from wounds inflicted by this hail several years before.

There had been thunder showers early in the morning, after which the air cleared up and became very warm. About 7 P.M., after a very heavy clap of thunder and vivid lightning, the hail began, and fell for about ten minutes only; *it consisted of balls of ice, of from* 6 *to* 8 *or* 9 *inches in circumference.* A small one weighed above two ounces; the form was an oblate spheroid, the nucleus the more transparent part. The cloud had an uncommon, fiery appearance, and there was lightning all the evening after. The next evening, also, much thunder, with heavy continued rain. On the third day, the air much clearer and fine; afterwards showery.

Hailstorm at Salisbury, June 21, 1817—Salisbury and its neighbourhood appears to have received the brunt of the storm. It commenced there about 2 o'clock P.M., with an almost instantaneous darkness, and a violent rushing of wind from north-east, accompanied by sheets of water, and large pieces of ice. About 3 the wind suddenly commenced blowing from south-west, with torrents of rain for more than half an hour. Lightning continued during the whole of the storm.

Tornado in Derbyshire, 1811.—On the 12th of May, about 5 o'clock in the afternoon, a destructive phenomenon appeared at Bonsall, in the Peak of Derbyshire. A singular motion was observed in a cloud of a serpentine form, which moved in a circular direction, from south by west to north, extending itself to the ground. It began near Hopton, and continued its course about five or six miles in length, and about four or five hundred yards in breadth, tearing up plantations, levelling barns and miners' cots. It tore up large ash trees, carrying them from 20 to 30 yards; and twisted the tops from the trunks, conveying them from 50 to 100 yards' distance. Cows were lifted from one field to another, and injured by the fall; miners' bubble-tubs, wash-vats, and other materials carried to a considerable distance, and forced into the ground. This was attended with a most tremendous hailstorm: stones and lumps of ice were measured from 9 to 12 inches circumference, breaking windows, injuring cattle, &c.

Hailstorm at Sheffield, 1811.—On May 19, 1811, there was a dreadful storm of thunder and lightning, accompanied with hail. The stones, which measured from 1 to 5 inches in circumference, were pieces of ice encrusted with frozen snow. The damage is beyond precedent. At Beauchief, a whirlwind tore up seven trees by the roots, broke several trees in the middle, many buildings were unroofed, and haystacks thrown down, *nearly all the water was carried out of Mr. Stead's mill-dam, and dispersed in the air.*

Saussure on the probable locality of Hailstorms.—The neighbourhood of this village [Borgo Franco in Piedmont] was visited on the 20th July, 1811, four days before our arrival, by a terrible hailstorm. The vines, torn to pieces and leafless, the maize in the fields partly laid flat on the earth, partly reduced to the appearance of broom-sticks, the trees in general stripped and broken, presented altogether a truly deplorable spectacle. *We were informed that the place was peculiarly subject to this calamity.*

It has often been observed in plains bordering on high mountains [Borgo Franco is so situated as to the Alps],* that at a certain distance from the mountains, hail is much more frequent than in places that lie somewhat nearer or more remote. *There are distances, too, that seem privileged, where it is very seldom that any hail falls.* My father has an estate on the *Arve*, not quite half a league from the foot of Mount Salêve, on which there has not been within the memory of man any considerable fall of hail, the stormy clouds passing always either nearer to the mountains, or at a greater distance.

Hail, we are certain, is necessarily connected with electricity. The clouds that deposit it are, therefore, unavoidably *charged*; and it should seem that, according as the electricity is similar or opposed to that of the mountains, they are either attracted or repelled thereby; and thus obliged to range at certain unequal distances from them.

Tornadoes.† — Two tornadoes passed in this vicinity on Saturday last (June 4, 1814), attended with their usual destructive effects on the timber, and razed the few buildings in their course to the foundations, destroying fences, corn, &c. In crossing the Ohio river, the water was taken out, and fish of every description were thrown upon the land.

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* Borgo Franco is near Ivrea, and about 40 miles south of the great chain of the Pennine Alps.

† From an American paper. Shawnoetown, Illinois Territory, June 9, 1814.

The courses of the two were nearly parallel and simultaneous, about 15 or 20 miles apart, proceeding from south-west to north-east. One passed through the prairies on Little Wabash, and was beyond our sight. The other passed in plain view, distant, on the first appearance, about three or four miles, and, from the levelness of the country, was visible for many leagues in its progress. Its shape was much like that of a cone, or sugar-loaf, with the small end downward, or rather like a speaking trumpet, its upper part flaring considerably as it joined the cloud above. It was as black as pitch, and appeared to boil like that substance over a furnace. The cloud above was also very black. The extent at the bottom of the tornadoes has been ascertained to have been between half-a-mile and a mile.

A singular circumstance, observed by myself, and others, who were within half-a-mile, was this —that the most vivid flashes of lightning were seen to pass between the heavens and earth in quick succession, just in front and rear, and sometimes through the body of the tornado (or perhaps around it, in a line from it to our eyes) and still no peals of thunder were heard from them. I do not think I ever saw so broad and vivid flashes before in my life. Indeed, I never before had so deliberate and fair a view of a phenomenon of this nature.

I will mention but one other circumstance—the hailstones which fell in these tornadoes were as large as a man's two fists. They were tried to be put into a pint tin cup, and would not go in. Hail of this dimension may be formed by being long borne up and driven round through a moist medium by the whirling wind, before being let down to the ground: whereas, by descending in a direct line, or nearly so, it can never become so large.

Extraordinary Hail.—On the 21st of May, 1828, in the Dep. du Gard, in France, there fell, about 6 P.M., an extraordinary shower of hail. After hard rain, about 4 the weather took up; the sun appeared at intervals, but was very soon again overcast, and a violent south-west wind drove the clouds very low and thick, which, rolling over each other without mixing, had the appearance of being swelled out by their mutual pressure. [The cumulostratus with a strong electrical tension, which, however, is internal, and not the pressure here supposed. See vol. ii., page 79.] Presently there burst out in torrents, a hail, which every one who witnessed it considered as most extraordinary—many of the hailstones being, without exaggeration, *of the size of one's fist clenched.* "I got two of them weighed (says the narrator), which I took at random: the one was 152 grammes [or 5 ounces], the other 130 grammes [or 4 ounces] covered with tubercles or blunt points, of the size of a little finger's end." They were transparent without, and had a whitish nucleus of 2 centimetres diameter; which in those I examined was hard, and not like a mass of snow. Some showed concentric zones, alternately opaque and transparent. They were elastic, and bounded several yards on a pavement. There fell with them some that were smaller, perhaps fragments of the large ones, and a great quantity of the size of a small nut, which had their origin probably in a different cloud, if it be true that all hailstones from the same cloud are nearly of one shape and size.

The *swiftness* of the descent was proportioned to the *magnitude*—the bigger seem to *slope* more in their fall: whether (says the author) they came from a greater height, or that the wind had more power on them. [It is plain these had more remaining *momentum.*]

While this hail was yet approaching, and while at some distance, passing away, there was heard a rustling noise. It lasted seven minutes only in the Commune of Hypolite de Caton, and took but a quarter of an hour to pass the whole space it covered, which was about ten post leagues in length. It ended at Lussare (a place to the north-west). The breadth of the track varied from 800 to 900 metres. It fell without rain, after a time of thunder showers, preceded by a suffocating heat.

Buckingham, *April*, 2, 1829.—Yesterday, about 4 o'clock in the afternoon, we had the greatest hailstorm, attended with a good deal of thunder and rain, ever witnessed by the oldest people in the neighbourhood. *Some time before the storm began, there were large masses of dense fog rolling horizontally and playing before the clouds.* The largest lumps of hail were about the bigness of a walnut, but it fell with such a tremendous roar, and so fast, that in the space of 12 or 15 minutes it was from 2 to 4 inches deep. Its general course seemed to be from the north-west to south-east. It has destroyed the window-glass as far as I have heard, and done considerable damage to the fruit-trees.

Here the quotations from Howard end.

3. HAILSTORM AT BONN, MAY 7, 1822.

On May 7, 1822, at Bonn,* hailstones 1·5 inches in diameter fell. Nöggerath says they had a concentric structure around an opaque white nucleus, the layers increasing in translucency as they approached the external surface. They had a fine stellular fibrous arrangement, with rows of radiating air-vesicles.

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* Kämtz's 'Meteorology.'

4. Hailstorm at Thourout,* August 11, 1852.

M. Ad. Tommeleyn, professor at the School of Agriculture of Thourout, wrote describing the hailstorm of August 11, 1852, at Thourout. After abundant thunder showers on the previous day, and a strong west wind, about 4 o'clock on the 11th the wind increased to a gale, heavy drops of rain fell, and there was much lightning. Soon a terrible hail shower succeeded. The largest hailstones were 7 to 8 centimetres in diameter, and about 75 grammes in weight; most were about 3 or 4 centimetres in diameter, and 40 to 45 grammes in weight. Their shape was generally that of an egg, some were flattened and angular; all had remarkable protuberances on their surface, and the largest were armed with points. The interior structure was curious; in the middle there was a more or less opaque nucleus; this was enveloped in concentric layers, mostly transparent and of unequal thickness. Rays, starting from the nucleus, crossed all the layers; their number varied between 8 and 14. The temperature of the hailstones was 2°·1 below zero (about 28° F.). Many small animals, such as pigeons and hens, were killed, and some persons were badly hurt.

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* Académie Royale de Belgique. Extr. du tome XIX, No. 9, des 'Bulletins.'

5. HAILSTORMS AT THE ORKNEYS, 1818 AND 1890.

In 1818, on July 24, a great hailstorm* took place at the Orkneys, its length being 20, and its breadth 1½ miles. The rate of progress was 1 mile in 1½ minutes. The duration at each place was 9 minutes, and the depth of hail 9 inches. The barometer fell 1·15 inches.

In October 1890, there fell the largest hail the observer ever saw, breaking 20 panes of glass. Half an hour after the shower they weighed ½ oz. each. Most of the stones were round, some pear-shaped.

Stewart relates† that stones fell of the size of a goose's egg, which broke even wooden window frames to pieces. The weight of the largest stones were estimated at 8 oz., and some penetrated the ground to the depth of 4 inches. Cattle were severely wounded, and many birds killed. The depth of hail in the open fields was 9 inches.

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* Thomson's 'Introduction to Meteorology.'

† 'Edinburgh Philosophical Journal,' No. 8.

6. Hailstorm in France, July 13, 1788.*

This storm is said to have begun near the Pyrenees, and to have passed right across France and Belgium. It advanced in two parallel lines, varying in width from 7 to 12 miles, and separated by a space of about 15 miles, in which only rain fell. Everywhere darkness preceded the hail. The rapidity of advance was 38 miles an hour, the duration of the hailstorm in each place about 7 or 8 minutes. The hailstones were partly angular, partly rounded, and the heaviest weighed about ½ lb.

7. Hailstorm in Oxfordshire, July 5, 1852.†

A thunderstorm with tremendous hail occurred in Oxfordshire on July 5, 1852. The hail was ¾ inch in diameter, ¼ inch thick, with a nucleus and five or six concentric layers. Some had four or five nuclei joined by a thin sheet of ice. At Nuneham no hail fell till the end of the storm, and then solitary bits of ice measuring 1¾ by 1¼ inches, regular ellipsoids, with a single nucleus, and a very rough coating containing many bubbles of air.

8. Hailstorm at Newark, May 7, 1863.‡

On the 7th of May, 1863, a hailstorm and hurricane occurred at Newark, remarkable for its small extent and great violence, and apparently of the nature of a whirlwind. Seen from a distance, it had the appearance of a waterspout. Its approach was signalised by an indescribable roar, a furious blast, and almost continuous lightning. Its breadth was 100 to 150 yards, its length three miles. Torrents of rain fell. The hailstones were of four kinds:—1. Hemispherical, clear like ice, except an opaque central point whence semi-opaque lines radiated along the base. Only a few of these fell. 2. Flattened spheres, semi-opaque, with hard white centre, thinner at the axis than at the circumference. 3. Opaque, pear-shaped, numerous. 4. Ordinary, circular, opaque, softish. On the falling of the hail, the air became chilly. The temperature fell 22·6 degrees in two hours at Highfield House Observatory. Some of the hailstones were 1½ inches in diameter and made bullet holes in glass, &c.

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* See Arago and others.

† Proc. Brit. Met. Soc., 1866.

‡ Proc. Brit. Met. Soc., June 1863, E. J. Lowe.

9. THUNDER AND HAILSTORM IN LONDON, AUGUST 19, 1867.[*]

This great thunderstorm was preceded by a day of intense heat, "which increased as the evening advanced." "The first peal of thunder was heard about 9, and from that time until after 5 A.M. on the 20th, it never ceased for more than a few minutes, while the lightning may be said to have been absolutely continuous. Rain fell in torrents, the drops being of enormous size and accompanied in some places by hail, which being driven against the windows by the violence of the wind, roused even the soundest sleeper. The storm was very violent in all parts of Surrey and in some parts of Sussex and Berkshire."

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[*] Newspaper accounts.

10. HAILSTORM AT GREENWICH, MAY 29, 1868.*

The morning of May 29 was very sultry, and dark clouds gathered in all directions. A slight shower followed at 11 A.M., with distant thunder. At 0h. 25m. P.M., the clouds began to mass together and to indicate that they were surcharged with electricity. Large drops of rain began to fall at 0h. 34m. P.M., and the storm approached with great rapidity from the south and south-west, speedily became localised, and raged with much violence from 0h. 38m. P.M. Heavy rain fell unremittingly, and vivid lightning and thunder occurred at brief intervals in all parts of the sky. Little change took place till 1h. 21m. P.M., when hailstones of large size fell with very great violence for four minutes and speedily covered the ground. These enormous hailstones were generally spheroidal in shape, and of variable size, the largest noticed measured 0·7 in. by 0·58 in., and weighed 33 grains. Their construction appeared to consist of four concentric layers of ice. After the hail had ceased falling, rain continued till 1.35, when the amount of water collected was 0·935 inches. At 2 P.M. every distant object could be seen with remarkable clearness.

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* Proc. Met. Soc., 1868. 'On the Remarkable Thunderstorm of May 29, 1868,' by W. C. Nash, of the Magnetical and Meteorological Department Royal Observatory.

11. HAILSTORM AT ASHBY PARVA, MAY 18, 1878.

On the morning of May 18, 1878,* a very severe hailstorm took place at Ashby Parva, near Lutterworth. In the early morning, thunder and lightning were frequent 9 or 10 miles to south-east, and occasional overhead, with gushes of moderately hard rain. This continued and gradually increased for two hours, spreading slowly towards west and north-west, while the clouds became increasingly stormy, though at a great elevation. Just before 5 A.M. the thunder and lightning increased in the immediate west and in the zenith. At 5.5 the sky had almost cleared (and very suddenly) in the east, while overhead hung one of the most awful-looking clouds that it had ever been my privilege to see. At this time the flashes were near, and between the claps a very loud roar could be heard overhead. It began to rain and hail with excessive violence. . . . Most of the hailstones were of the size of small hazel-nuts, but mingled with these were others as large as walnuts. About one of these fell on every square foot of surface. At 5.10 the surface wind veered to south-south-west, and at 5.15 the storm ceased, thunder and lightning continuing, but moderately, in north-east and east. As much as 1·89 in. fell in this storm. . . . As far as I can learn, but little hail fell at any of the neighbouring villages from two to three miles distant in several directions. The barometer fell steadily, and I could not see that the mercury was affected by the down-rush of water. . . . At 10 A.M. of the 25th a very violent thunderstorm broke over us from north-west, the hail, which was large and hard, completely covering the ground. At 11 we had again a violent hailstorm, but without thunder.

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* Symons's 'Meteorological Magazine,' 1878. 'Heavy Local Hailstorm.' Letter by the Rev. Clement Ley.

12. HAILSTORMS IN JUNE 1878.

On June 23, 1878,* a very heavy thunderstorm with large hail occurred at Croydon and other places. In the greater part of Sutton all skylights, frames, hot-houses, &c., had all their glass broken. Five hailstones were said to have weighed a pound. In 2¼ hours, 1·82 in. of rain fell. A large number of places were struck by lightning. The temperature had reached its maximum for the month, 90°, in south London on June 22.

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* Symons's 'Monthly Meteorological Magazine,' 1878.

At Haverfordwest, on June 29, at noon, a very heavy thunderstorm began, and hail fell in the form of irregularly shaped pieces of clear ice, some an inch in length.

"At Ashby Parva, on June 26, the morning was cloudless. About noon, a few high cumuli began to be scattered over the sky, moving from south by west. About 1 P.M. the cumuli rose to a large size in the west and increased steadily. At 3 P.M. there was nimbus and thunder in the west. Cumulus travelled slowly from west, and cirrus, which began to be visible above, from north-north-east. At 4.25 very heavy hail fell. The wind suddenly rose and went completely round the compass twice in about ten minutes, blowing, especially from the south, with extreme violence. The tornado was accompanied by a deluge of rain and hail. The barometer was very steady and high during the storms."—(C. Ley.)

13. HAILSTORM AT NEWPORT, ISLE OF WIGHT, AUGUST, 25, 1855.

At Newport, Isle of Wight, on August 25, 1855,* soon after 11 P.M., a most terrific storm broke over the town. For nearly half an hour pieces of jagged ice fell, measuring 3 to 7 inches in circumference. Hundreds of birds were killed and glass and vegetables destroyed.*

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* Symons's 'Monthly Meteorological Magazine,' 1878.

14. HAILSTORM AT ASHBY PARVA, AUGUST 4, 1878.

"At 8 A.M. on August 4, 1878, at Ashby Parva,† wind was north-east, and light, with a rapid east upper current. Nine hours of generally bright sunshine succeeded, during which the breeze went round to south-south-east, while the cirrus current backed to north-east. Cumuli of very high, narrow, and fantastic forms hung about the sky, and at 3.30 P.M. a local thunderstorm broke in distant south-south-west, and travelled slowly off to west. At 4.30 a yellowish appearance began to be noticeable all over the southern sky, and in a short time a bright orange-coloured bank of cirrus appeared over that horizon, running up in filmy threads towards the zenith, the edge moving rapidly from east-south-east. Beneath the bank were vast towers of inosculating cumuli. Thunder commenced at 3 P.M. in south-south-east, and from that hour to 5.45 the storm rapidly approached, apparently greatly increasing in intensity, lightning being exceptionally vivid. When about two miles distant, the peculiar roar of hail could be heard between the crashes of thunder. . . . . In a quarter of an hour hail covered the ground to the depth of two inches. . . . . Windows facing south-east were generally smashed. The hailstones were exceptionally round and hard. Two hours after they fell, some were 4½ inches, and one 5¼ inches, in circumference. At 8.30 P.M. the storm presented itself in the west as a bank of cirrus moving from a north or north-east point. The area of the great hail was found to have been small in extent."—(The Rev. C. Ley.)

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* *Hants Independent*, August 25, 1855.

† Symons's 'Monthly Meteorological Magazine,' 1878.

15. HAILSTORM AT RICHMOND, AUGUST 3, 1879.*

This great hailstorm was investigated by Mr. Symons, and was described in the local newspapers. Mr. Symons says: "We incline to the belief that this hailstorm was nearly as remarkable for its large extent as for the size of the hailstones, or the damage done. . . . The usual area which we should assign to an English hailstorm is a mile or two long and a few hundred yards broad." In this case, "we have damage from one mile south of Kingston to a little north of Ealing, or seven miles from south to north, and an average breadth of two miles. This gives an area of damage equal to 14 square miles, which far exceeds any case we can recollect." Many short accounts of the hailstorm and its damage follow, from a number of different places. At Gower-house, Teddington, a hailbolt which fell through a carpenter's window was found by him to be 4½ inches in length. At Halford House, Richmond, four hailstones weighed together 1 lb., and holes up to 2 inches deep were made on the lawn. At one place a zinc roof was pierced, at another an iron roof scored, and at Kew Observatory the anemometer cups were knocked out of shape. At Teddington the hailfall lasted about 15 minutes. The hailstones quite covered the ground and seemed to be as large as nutmegs, but at intervals were much larger ones, which stood out among the rest like "rocks among pebbles." Some of the stones must have had jagged edges. "I have heard much louder thunder, but never seen more continuous or more blue lightning." The previous evening was cool, with a north-east breeze. At Kingston hailstones were picked up by the Inspector of Police which were 5 inches in circumference. At Orleans-road, Twickenham, even some slates were perforated, and thick glass pierced with clean circular holes; large boughs twisted off trees, and plants cut down as with a knife. At Orleans House, the lawn was indented with thousands of holes an inch or so in diameter and over an inch deep. A correspondent from Church Road, Richmond, describes the lightning as constant from 9 P.M. to nearly 3 A.M.,

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* Symons's 'Monthly Meteorological Magazine,' 1879.

"the most continuous, for so long a time, I ever saw. There were occasional downpours of rain, with violent gusts of wind from east and north-east; about 1.50 there was the most violent hailstorm I ever recollect, lasting about 10 minutes; the hailstones were of very large size, nearly all I saw being in the shape of flattened spheres, like the common acidulated drops. . . . In many cases the stones have gone clean through the glass like a bullet." At Richmond Police Station, Inspector Pearman drew the outline and the usual shape of the stones; it is oval, 1·6 inches by 1·3 inches; these, if ¾ of an inch thick, would about equal spheres of 4 inches circumference. At St. Margaret's, Twickenham, some of the indentations on the lawn were as large as the bowl of a large wine-glass. At Kew Observatory it was noted that thunder and lightning began about 1.30 A.M., and hail fell about 1.50, rain having been falling since 0.50 A.M. The hailstones averaged from an inch to an inch and a half in diameter. The Observatory was near the edge of the storm, and the wreckage was less than at Richmond. The barometer was not much disturbed. One assistant remarked the absence of forked lightning, and timed one continuous roll of thunder for 20 minutes without a break. At Dunster Lodge, Isleworth, Miss Ormerod reported that the cloud currents had been seen to be variable during the day (August 2), vivid lightning was first noticed at 11.20 P.M., and from 0.45 to 2.30 A.M. continued almost without any intermission in sheets of light over the whole observable part of the sky. Thunder was pretty constant, but not in heavy peals. At 2 A.M. the hail broke some windows; some of the hailstones were of the usual shape, and some were pieces of ice with jagged edges. The largest piece of ice measured was 5¾ inches in circumference after being held in the hand for about 3 minutes; it was clear outside and milky in the centre. At 2.10 A.M. a single long gust of wind, lasting about 4 minutes, passed by with a heavy rushing sound. At Hanwell "large balls of ice came dashing through the windows like rifle bullets." The largest measured 5 inches in circumference and weighed about ¾ (?) of an ounce. At Harrow the hailstorm broke just after 2 A.M.; the hailstones were mostly spherical in form. The largest was over 2 inches long, and 1½ inches broad. At Stoke, near Guildford, and many other places there was an "awful thunderstorm" from about 11 P.M. to past 1 A.M. "I never saw the like before—one continued blaze of light and one continuous roll of thunder." At Beech House, Cambridge, rain fell to the amount of 3·6 inches. "There were about 56 flashes every minute." At Granchester Mill the rainfall was 3·92 inches. The barometer was high, 30·10. At Cambridge, at 3 A.M. there were 120 flashes of lightning per minute. At Cambridge

Observatory a very severe storm raged from 1.45 to 5 A.M. The sky was blazing with incessant sheet and occasional forked lightning. The barometer and wet and dry thermometers were nearly stationary throughout. It was considered that the first storm came up from the south-west, being the upper strata, whilst the lower was moving from the east. The first storm, from 10 to 11 P.M., had been characterised by a continuous roar with rain, thunder, and wind. At Kirkham, Babbacombe, Torquay, the wind on the morning of August 2 was east-north-east, clouds coming from south-south-west. At 3.27 P.M. there was a thunderstorm. Very heavy rain, and some hail, fell a little before 6 P.M. A great thunderstorm, with almost incessant lightning, raged after 11.18 P.M. The barometer fell from 30·06 at 2 P.M., on the 2nd to 29·84 at 0.35 A.M. on the 3rd. Temperature was about 58, wind east-north-east, strong. Clouds came from south-south-west.

The Hailstorm of August 3, 1879, *at Richmond, Surrey.** — This, by far the greatest hailstorm which has occurred in my experience, broke over Richmond, Kew, and Twickenham, about 2 A.M. on the morning of August 3. It took place in the midst of a thunderstorm, but although there had been much lightning little rain had fallen. The first announcement of the fall of hail was some loud thuds on window bars and sills; this was quickly followed by the crash of glass from skylights and windows falling on the staircases. In one room on the east side of the house 11 panes were broken. On looking out, the almost continuous illumination of the lightning showed large irregular blocks of ice lying on the ground among hail of lesser size. In the morning it was found that the hail had broken nearly all the glass in the roofs of greenhouses and in frames. Frames which were protected by matting were not quite exempt, for the matting and the glass under it were pierced by large holes. In the town of Richmond, windows on the east side of houses were broken.

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* MS. Notes, R. Russell.

16. Hailstorms at Wilmslow and Reading.

On June 25, 1888,* at Wilmslow, hailstones fell as large as guinea-fowl's eggs, and were found to be ¾ inch in diameter 7 hours later. At Guildford much glass was destroyed. On June 13, there had been a snowstorm in Cornwall, and at Callington, in that county, the hail was so large that twigs were cut off.

Hailstorm at Reading on August 24, 1890.†—From about 5.25 P.M. hail fell for 15 minutes, of the size of large peas. The minimum temperature of the previous night had been very low, 40° at 5 feet from the ground.

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* Symons's 'Monthly Meteorological Magazine,' 1888.

† Op. cit., 1890, C. N. Pearson.

17. PHENOMENA AT HASLEMERE, SURREY, IN CONNECTION WITH HAIL.*

August 24, 1889, *Haslemere.*—Wind had been westerly on Saturday, 23rd, with extremely grand detached cumulus clouds; these had hard, sharp outlines, and were rolled and heaped. The sky was deep blue and there were no showers. On 24th, fine morning with cumulus clouds. Clouds all the morning in three different layers, one, lowest, from about south-west, next above from west-south-west, and highest from south-south-west by west, or thereabouts, but all these directions varied. A few small cirrostratus above from south-south-west. Various currents evidently overhead, and a slight mist later on as of thunder-weather. At 1.35, dark cloud overhead and eastwards, and a few large hailstones at about 4 or 6 inches apart. Towards east, over the Haslemere direction, very dark cumulus, and shreds of cloud hurrying apparently towards a centre, below the darkest part of the heavy cumulus; there, about 2 miles off apparently, a circulation was kept up for an hour, nearest low shreds coming rapidly from north, and further shreds from south. These rags of cloud seemed to be always dissolving and re-forming, and to be borne somewhat upwards. There seemed to be a heavy storm, and there was thunder further north-east. After about 1½ hours, a heavy shower fell, lasting one hour. A very heavy hailstorm occurred at Teddington, Middlesex, in the afternoon.

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* MS. 'Notes of Phenomena seen at Haslemere in Connection with the Production of Hail,' R. Russell.

August 29.—To-day fine, but heavy cumulus occasionally, remaining in one place, south-west, during afternoon, with apparently heavy dashes of rain in distance. Evening: wonderful effects of long bank of *turreted* cumulus in east, north-east, and south-east, and below this a remarkable semi-transparent blue haze (*red* by transmission). Persistent redness on these clouds at sunset. Dry lower air.

N.B.—There were heavy hailstorms at Herne Bay and storm at Dover in the morning, and showers during the day.

September 21.—This morning, about 6.30 A.M., I observed in the east a quantity of turreted cumulus in a bank, but not so extraordinary in appearance as on *August* 29. It lasted some time, but the day was only grey and threatening, with south-south-east wind till about 1.30, when it began to rain slightly. This continued till about 5.30, with an interval. About 5.30 there was a heavy shower; about 6.30 a heavy thunderstorm. The turreted cumulus in the morning seemed to portend hail, and was noted for hail at the time of observation.

September 22.—Accounts of heavy thunderstorms in Paris and France. At Marseilles, tremendous hailstorm and lightning 6 to 8 A.M. on 21st.

August 4, 1891, was remarkable for heavy storms, borne by a south-west wind, passing both south and north of the point of observation at Haslemere. The rain was seen descending in the distance in nearly vertical lines, showing no great difference in the velocity of the wind at different altitudes. The cumulus was very massive, and was surmounted by grey or white cirrostratus. The altitude of the cumulus was very great, insomuch that in the evening, when a considerable descent and dissolution of cloud had occurred, as on previous evenings, a towering cumulus was found to extend to an altitude indicated by the sun's rays still shining on its apex 16 minutes after sunset. Heavy hailstorms passed over the Lower Thames Valley, in the neighbourhood of Chertsey, in the afternoon. The weather, according to the Official Report, was in a very unsettled and showery state in nearly all districts, with thunderstorms at some of the English and Irish stations. A depression over the north of England was moving slowly southwards, and wind was north-east in north-east England and Scotland, northerly in Ireland and the south-west of

England, strong from west over the eastern parts of the Channel, and light from south-west in the east of England. On the following day, August 5, the depression in the north of England was filling up, but the condition of the previous day over southern England returned in an aggravated form after a clear fine night. The wind in northern England and Scotland was north-east, and over southern England, south-west. The morning was fine and cloudless in Surrey, but by 9 o'clock some small cumuli from south-west were passing across the sky, and in the course of the next few hours cumulus rapidly increased. About 10·30 A.M., the first shower occurred. In the afternoon a great part of central and southern England was subject to heavy thunderstorms. The rainfall at Westminster was 0·33 inches, and at Hillingdon, in Norfolk, 0·83 inches. Thunderstorms were severe from Gloucestershire in the west to Norfolk and Kent in the east. The temperature in London, which before the storm was 67, fell after it to 56. The following night was fine but misty near the ground.

The atmospheric condition giving rise to these storms was not obscure. Hillingdon, where the fall of rain reached the enormous amount of 0·83 inches in 20 minutes, from 3.15 to 3.35 P.M., was situated near the centre of a small depression, having to the north of it north-east winds, and to the south-south-west winds.

At Shields thunder and lightning had set in at 9 P.M. on Monday and continued till 8 A.M. on Tuesday. At 6 P.M., a large trough of low pressure reached from the south of Sweden over Denmark and the North Sea to the coast of Ireland, and within this large area there was a continual tendency for the formation of shallow local depressions. In Ireland the wind was northerly, and the air was cold both there and in Scotland. It is clear that in such a distribution of pressure and wind there would be an interference of currents of different temperature and humidity, and that the colder wind in the north would tend to invade at certain points the south-westerly breeze of the south of England. Invasions would take place where friction and opposition were least, certainly not near the earth's surface, where, owing to heating of the land by the sun, the breeze from the sea would be stronger.

Between the north-east and south-west winds there would be an area of light winds and calms, similar to the equatorial region of calms, in the development of vertical rather than horizontal currents. The heaviest storms would take place in this area, and would occur in the hottest hours of the day. The evolution of storms of this kind thus seems to depend on two main factors, the opposition of winds within a moderate area, and the ascent of warm into cold air, or the descent and mixture of cold with warm air; in southern

England, where the cold air was uppermost, the equilibrium was most disturbed during the day, while at Shields a storm continued throughout the night. Heavy showers of the kind experienced over southern England, with towering cumulus, may be taken as almost certain evidence of the co-existence of a cold and not strong current at a height of a few miles above the earth's surface, with rapid increase of the temperature of the lower air and of the sun's rays, or else with a state of high temperature of a mass of lower air. Visibility was very great on Monday, 3rd.

The condition preceding the *Royal Charter* storm of October 25th, 1859, was in some respects analogous on a much larger scale. "Hail and snow in the north, clouds and rain in the south, prevailed before the *Charter* gale; and this wintry weather on October 21 seems the more remarkable because so rapidly following very warm if not hot weather." (Fitzroy.) On October 19, at Belfast, it was oppressive and close. On October 21 it was exceedingly cold, the air was remarkably transparent, and there was much vivid lightning.

Hailshower at Haslemere on April 26, 1892.*— The evening of April 25 was fine; during the morning there had been rain with a south wind veering to west. The morning of April 26 was very fine. Small cumuli appeared at 8 A.M., with hard rounded edges, indicating showers. The temperature at 8 A.M. was 42. Cumuli grew rapidly and formed layers at different heights, moving in somewhat different directions. The upper parts of the clouds eastward were white, the lower grey and darker. Cumuli soon appeared, with white veils of thin cloud partly obscuring them. At 10.25 there was a shower lasting six minutes, beginning with small melting hail and ending with rain. A strong wind blew before the shower and quickly abated; the air remained cold.

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* MS. Notes on Weather, R. Russell.

Observations at Haslemere on May 25, 1892.—About 6.30 A.M. sharp thunderstorm, with heavy rain and hail for three minutes. The sky then cleared. Clouds highly characteristic of thunder-weather, with south wind. Small, hard, round-edged, compact cirro-cumuli or cumuli scattered over a blue sky at a great height, moving from south. About 9, or 9.30 A.M., a heavy thunder-cloud passed from south to north, some miles eastward. I watched it carefully for 20 minutes. It consisted of an immense mass of cumulus, towering to a height estimated at fully 40,000 feet. The sun was on the west of it, and illuminated many cloudlets below the massive cloud, and also illuminated a white nimbus like a halo about the head of the cumulus mass. Some of this white veil-like cloud was below the head of the cloud in a sheet or band, and displayed rainbow tints against its dark background. The outline of the white nimbus over the head was that of a half-circle. The highest cumulus mass had several layers below it; the greater part was at a vast height, and seemed scarcely to move at all in comparison with the lower clouds. It moved, however, compactly and slowly, northwards. Other small cumuli were seen southwards, and some were of the towering form seen in hail-weather. A small shower fell about 8.45 A.M., with a sudden very strong wind from south. The clouds dissipated during the day with a moderate south wind, but in the evening (9 P.M.) collected again, and there was a great display of lightning towards east and south. The flashes were invariably multiple, very brilliant, and one formed a kind of gyration in mid-air, causing the appearance of a globe of glowing mist round about it. Few flashes were near enough for thunder to be heard, and these belonged to offsets of the main storm, which I calculated to be 40 to 60 miles eastward. To-day (May 26) the papers report a tremendous thunder and hailstorm at Brighton, about 40 miles east, last night.

18. HAILSTONES AT CLERMONT,* JULY 28, 1835.

At a quarter past 2 the anterior part of this cloud was very near Clermont; the noise which had been heard for some time had become more intense, and I perfectly distinguished a very rapid movement in the borders (edges) of the cloud. The borders seemed to undulate, but from the position in which I was, that which appeared to me to be undulations must have been caused by a strong agitation. . . . I shall not describe in detail the terrible effects of these hailstones; it is enough to say that branches of trees of 2 inches in thickness were completely broken, etc. etc. . . . Finally a part of the beautiful stained glass windows of the cathedral of Clermont was destroyed in a few minutes, after having stood for at least four centuries without such an experience.

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* 'Observations on Hail,' H. Lecoq. 'Annales de l'Académie de Clermont,' vol. ix., 1835.

Their (the hailstones) average size was that of a hen's egg; but some among them were as large as a turkey's egg. . . . They were mostly covered with crystals, some of which still showed signs of hexagonal prisms terminated by pyramids with six facets.

The centre of the hailstones was formed by small grains of white ice, opaque and fibrous.

The storm arose on the ocean about 10 A.M., and the hail began by doing havoc in a part of the island of Oléron.

Hailstones fell in several places, varying in size between small and large nuts.

At 2 o'clock large ice fragments fell on the lava near the Puy de Dôme, and broke on the rocks.

At 2.15 to 2.30 the hailstorm finished its career at Clermont and Montferrand. Total length, 90 leagues. Everywhere the wind was the same, that is there were two winds superposed, crossing at right angles, north to south, and west to east. The intensity of the storm grew as it progressed. At first the hailstones were small, round, and few. Towards the height of intensity the stones were ovoid, and about 6 to 8 oz. in weight. The storm-cloud was very low in the Department La Creuze, for it was below the top of the Puy de Dôme, which had no hail, but it fell on the Little Puy de Dôme, about 3700 feet high.* Animals at this height were hit, not frightened or hurt, but there were accidents 600 feet lower down, horses taking fright. The hailstones on Little Puy de Dôme were driven by a rapid extremely cold wind. On the flanks of the Puy de Dôme. the trees were uninjured; a little lower down, the leaves were torn, and, lower still, branches were broken.

Storm of August 21.—Summit of Puy de Dôme. West wind, clouds coming from south. As long as the two layers of clouds were not superposed, there was no hail; those from south were lowest; the clouds heaped up, and at last at one place rain poured down. The south wind became strong and very cold. Lightning passed frequently in the lower cloud. A whirling movement in the borders of the clouds took place, and an apparent electric repulsion of the hail.

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* It seems questionable whether the fall of hail was thus limited by the height rather than by the situation of the higher mountain.

Among the conclusions arrived at by M. Lecoq are these:—

1. That in hailstorms there are two layers of clouds and two different winds.

2. That electricity plays a great part in the production of hail.

19. Hail in Switzerland.—Colladon.*

On July 7 and 8, 1875, hailstorms passed over several districts in Switzerland. The first started about 10 P.M., from the banks of the Saône, passed Geneva about midnight, and reached St. Maurice about 2 A.M. on the 8th. The second started at noon from the Pont de Beauvoisin, and died out about 3.15 near Sion. Both these storms passed over chains of mountains from 4500 to 6000 feet high, without notable change of speed or direction. Some of the mountains crossed are covered with forest. Other storms occurred about the same time in France and Switzerland, and the extraordinary forms of cumulus caused anxiety. On July 7, there were hailstorms near Lucerne, Zurich, and Argovie, and near Bâle and Neuchatel. Hail fell at Orleans, and a waterspout caused great damage in Calvados. On July 8, hail ravaged the environs of Embrun and the borders of Durance, and hail fell in a large part of the Ardêche, at Montmeillan, and in parts of the Department of Isère. The hailstones on the 8th, in Switzerland, were compared in size with walnuts, pigeons' and hens' eggs: all were nearly round or ellipsoid, but flattened. This uniformity is not always observed. In the storm of July 7, walls were everywhere struck on the same side, showing absence of gyratory movement.

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* 'Contributions à l'Étude de la Grêle,' Prof. D. Colladon, Geneva.

On August 23, 1850, a part of the Canton of Vaud was devastated by successive falls of hail at intervals of some minutes. The hailstones in the several falls differed from each other, being in one round or oblong, in another furnished with crystalline forms like rock-crystals.

M. Colladon describes the hailstorm of June 5, 1877, and notes that on that day the heat was overpowering at Geneva. At 5.45 P.M. a great thunderstorm arose from south-south-west. The flashes were 7 or 8 to the minute, and seemed to strike the ground or the lake. At 5.58 large drops fell, then a violent shower: at 6.5 hailstones fell copiously, nearly spherical, 10 to 17 mm. in diameter, having a snowy nucleus 6 or 7 mm. in diameter, surrounded with two layers of ice, the first transparent, the second somewhat opaque. The top of the cloud above the storm, when it had passed over, seemed to show a convergence of currents towards the lofty cumulus from which hail fell. The hail was seen to fall chiefly in two places on the lake, each of which was under a cumulus arising out of the nimbus.

20. HAILSTORM AT OBER GRAINAU, BAVARIA.*

At 10 minutes to 4 there was a long loud peal of thunder, and the whole valley was filled with falling matter, which proved to be large hailstones. These fell for 7 or 8 minutes without any rain, thunder, or lightning. The storm ceased suddenly, as it began, and as a few large stones fell at the close there was a light misty rain. The average size was 1¼ in. in diameter. The general form was round or oval, but some of the shapes were most extraordinary. Some of the stones were opaque like porcelain, others semi-transparent with a nucleus, and not a few perfectly transparent and clear. The surface of one was covered with small lumps like boiled sago. Its size was 2½ inches long, 1½ wide, and 1¼ thick, and its weight at least 2 oz.

21. HAILSTORM IN FRANCE, APRIL 4, 1877.†

Dark clouds had gathered and the storm was imminent at 2 P.M. Two layers of clouds were well distinguished, one high, almost motionless, the other low, black, and moving rapidly from south. Thunder was heard. At 2.8 the first drops fell, at 2.20 the drops were enormous and thick together; the air was still. From 2.25 to 2.30 hail fell, then heavy rain. At 2 P.M. the maximum temperature was 19° C. At 2.30 P.M. the temperature had fallen to 11. At 2.30 the wind was violent from south to south-west. The hailstones were all of the same form, derived from the spherical pyramid; the length of axis was from 25 to 30 mm.; the stones were composed of alternate opaque and transparent bands, the outermost being transparent. Sections perpendicular to the axis, as well as parallel to it, showed the bands. Some of the stones were circular at the base, others hexagonal. The weight varied from 4·7 to 6 grammes. At 5 A.M. on April 5 the temperature was 5° C.

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* Account by Colonel Ward in Symons' 'Monthly Meteorological Magazine,' December, 1882.

† 'Comptes Rendus;' 1877, Godefroy.

22. HAIL AND COLD IN SWITZERLAND.

In the storm of August 23, 1850, in the Canton de Vaud, the air was extremely cold, not only where the hail fell, but also in surrounding districts.*

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* Dufour on 'Hail.'

23. Top-shaped Hailstones.

Mr. C. S. Middlemiss described [*] a fall of hail near Ramnagar, Terai, India, in which the hailstones were " top-shaped," or conical. The broad end was composed of uniform ice, the pointed end of alternate clear and white bands. Mr. C. Smithson described [†] a hailstorm near Rochdale during which two waterspouts were seen. " Top-shaped " stones fell, consisting of alternate cylinders of clear and white ice. Mr. Alex. Johnstone stated [‡] that top-shaped hailstones which fell on May 6, 1884, showed a radiated fibrous structure, but he had since found hailstones radiating from the apex.

24. Hailstorms in North America.

Loomis states [§] that in North America hail seldom falls except during thunderstorms. It falls at the commencement of a storm, or in the course of it, but not after a storm. An extraordinary rise of temperature in April or May often precedes a hailstorm. The formation of hail is invariably attended by two currents of air, of which one is very hot and the other icy. The warm current appears to be forced upwards on meeting the cold current. Hail seems to be formed, according to Loomis, by the rotation of the air about a horizontal axis, so that the frozen drops are alternately forced into watery and snowy cloud. He calculates that a drop

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[*] *Nature*, March 3, 1887.

[†] *Nature*, March 10, 1887.

[‡] *Nature*, April 7, 1887.

[§] Loomis' 'Meteorology,' 1873.

$\frac{1}{4}$ in.	in diameter falls	34 ft.	a second, or	2040 ft.	a minute,
$\frac{1}{25}$ in.	„	13 ft.	„	780 ft.	„
$\frac{1}{75}$ in.	„	8 ft.	„	480 ft.	„
$\frac{1}{1000}$ in.	„	2 in.	„	20 ft.	„

and that a hailstone 2 inches in diameter would fall 18,000 feet in two minutes, that is, 9000 feet a minute. This is a much higher rate than that estimated by Plumandon and others. At an elevation of 18,000 feet above New York, the average temperature in summer is 20° F.

25. HAILSTORM IN MINNESOTA, AUGUST 18, 1858.*

Mr. Nathan Butler communicated to the "Bulletin" of the Minnesota Academy some notes on a hailstorm which he experienced in the western part of Minnesota, on August 18, 1858. The sky was generally clear, the weather quite warm, and the clouds overhead very light and fleecy. Immediately following a flash of lightning large hailstones began to fall, and continued for perhaps two or three minutes. They buried themselves for about half of their diameter into the sod of the prairie. When the shower was finished, the stones were sprinkled into the ground about 15 feet apart, and the larger ones were about the size of a man's two fists. [Has not a magnifier been used here?] In shape they were spherical at one end, made up of hexagonal crystals, like crystals of quartz; the other end was conical, made up of white ice. They were quite solid and did not break in falling. They were found to weigh a pound each.

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* 'Physics of the Globe,' Cleveland Abbe, 1878.

26. HAILSTORMS IN THE THRIAL MOUNTAINS, ETC. —ABICH.

A hailstorm occurred* on May 27, 1869, in which arched cumulostratus was observed in masses heaped above each other. Balls of ice fell as large as small apples, at first singly, then more thickly. Each was composed of layers of transparent and milky ice. The kernel was about the size of a nut, and was partially transparent. Some had no distinct kernel, and on some there was a six-sided pyramidal whitish growth. From the kernel six rays reached to the circumference, separated by an angle of 60°. The ice was sprinkled with little air-bubbles, drawn out to long and fine vesicles, their long axis radiating from the centre. The storm was about a verst broad.

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* 'Über Krystallinischen Hagel im Thrialetischen Gebirge,' H. Abich, 1871.

Storm of June 9, 1869.—The stones which fell on June 9 were covered with clear rhombohedral crystals. Most of these crystals belonged to the form of six-sided columns, with blunt rhombohedral ends, yet some were projected freely 15 mm. long. Many crystals with expanded ends and dihexahedral ends were seen.

Storm of August 24, 1869.—All the morning there was a misty obscuration with a north-west wind. There was a sudden furious burst of wind from north-west and a heavy hailstorm occurred. Branches of trees were broken at various heights. The temperature fell 4° C. from August 23 to 24.

Storm of September 12, 1863 (*Observations of A. Nöschel*).—At 2 P.M. a storm arose over the German colony of Marienfeld, 36 versts east of Tiflis, exhibiting nearly black and sharply-defined clouds. It lightened and thundered, and there was a noise in the air; soon it rained, the drops being at first large and cold, then smaller, mixed with ordinary hailstones. Suddenly the rain ceased and the hailstones became larger and thicker together. Lastly there fell with a rushing noise pieces of ice up to the size of pigeons' eggs, with such force that they rebounded three to five feet from the earth. In 15 minutes the whole visible plain was covered with hail five inches deep, and the temperature had fallen from 20·2° R. to 9·8° R., or about 20° F. The hailstones consisted chiefly of elliptic lens-shaped pieces of ice, mostly transparent, but partly snow-like. Only a few consisted of blunt pyramids of clear ice resting on a snowy base. The hailstones were made up of small six-sided discs, with a particle of snow in the middle, whence proceeded six rays; thus it seemed as if the ellipsoid lens-shaped hailstones were a conglomerate of six-sided discs. But these, on being broken, showed no trace of crystalline arrangement. It seemed, indeed, that the crystalline formation was only on the surface of the stones, for a point was soon reached in the melting when there remained only clear ellipsoidal lens-shaped ice, like eyes, with white pupils.

Storm of July 7, 1769, *near Paris.*—A thunderstorm, brought by the west wind, was accompanied by hailstones formed like six-sided pyramids, with very blunt ends, six lines long and three broad. When the wind shifted to north-east the stones became convex lenses, nine lines in diameter, and so regular that the landscape seen through them was evenly magnified.

On the 4th July (year wanting), a great thunderstorm took place over a large part of Western France. Enormous hailstones fell at Angers, penetrating the tiled roofs of houses and making round holes, killing animals, and breaking off branches. When broken, with a section passing through the centre, these spherical hailstones were found to contain a small spherical kernel, surrounded with a somewhat opaque shell of bluish ice, with traces of concentric layers, and rays from the centre to the circumference. These hailstones were encrusted with large pyramidal projections, between which were smaller ones. Herr Abich observed hailstones, which fell at Bjeloi Kliutsch in 1869 and 1870, which presented similar features to these, especially the central sphere of compact ice, covered with free prismatic crystals. Sanno Solaro describes the hail which fell at Bari, in Italy, as composed of opaque whitish ice containing long irregular air-bubbles, and of rings of clearer ice, containing very much smaller bubbles, the exterior surface of the stones was rough and irregular.

Dr. Mann gives the following account* from Abich's description of hailstones which fell near Bjeloi Kliutsch, a short distance south of the Caucasus, on June 9, 1869. "Some of the hailstones were nearly 3 inches in diameter and weighed 4 oz. They contained a central mass of pure white ice, rendered opaque by the infiltration of minute air-bubbles. This mass was most opaque in the middle of the central nucleus, and in an outer investing shell, and between the opaque kernel and the shell there was more transparent ice, marked radially by six spoke-like lines of a glistening hue, and inclined to each other by quite regular angles of 60°. The glistening rays lost themselves gradually in both the inner nucleus and in the shell. The entire central mass was compressed at the sides, and was surrounded along the circle of largest diameter by a zone or wreath of large crystals of bright transparent ice, which were, for the most part, of exquisitely regular geometrical symmetry. Some of these large crystals were quite distinct from the rest, whilst others were connected by their sides. The greater part of them were moulded into the form of six-sided columns, with obtuse rhomboidal prisms capping their ends. But there mingled among these other broader varieties of more or less flattened and tabular shape, and often rounded away by incipient fusion. As a rule, the outward or longitudinal growth of the crystal appeared to have occurred in a plane corresponding more or less nearly with the rim of the wheel-like flattened mass. But occasionally well-developed crystals appeared also on the flattened sides of the spheroidal mass, and when detached from it left pits on its surface which corresponded with the completion of the pyramidal forms of crystallisation in that direction." The largest crystals are represented as longer than the diameter of the central mass. Crystalline hail very similar in construction was described by Captain Delcros as having fallen in the western provinces of France on July 4, 1819. The central mass was completely covered by clear crystals.

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* *Science for All*, edited by Dr. R. Brown; Article by Dr. R. J. Mann, on 'Hailstorms.'

27. HAILSTORM IN RUSSIA, JULY 11, 1863.

Of the great Russian hailstorm of July 11, 1863,* Mr. Howard says that before the storm the weather was very hot and gloomy; the wind rose, "dense columns of black smoke rose in conical form from the earth," hailstones 4 inches in diameter fell; houses and trees were levelled by the wind; a post, 31 feet high, 9 feet in the ground, 11 inches in diameter at the base, was lifted whole out of the ground; two large stones were carried up from a ravine on to level ground, and children were carried through the air.

Mr. Donkin relates of the same storm that it was 700 feet wide, and that iron sheets were carried 24 miles by the violence of the wind.

28. HAILSTORMS IN INDIA.†

There is no account of occurrence of hail within 1000 feet of the level of the sea south of Lat. 20°, though just to the north of this, hailstorms are very abundant, and they occur very frequently south as far as Ceylon at altitudes of 1700 feet and upwards. They seem most frequent during February and May; rarest during the rainy season. The hailstones exceed in size those of Europe, and are often larger than apples or oranges.

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* Proc. Brit. Met. Soc., January 1865, W. Howard.

† 'Transactions Bombay Geographical Society'; Extracts from 'A Catalogue of the most Remarkable Hailstorms which have occurred in India betwixt 1822 and 1850.'

On April 10, 1822, near Bangalore, a thunderstorm took place, followed by a hailstorm in which the hailstones were fully 3 inches in diameter. Large numbers of bullocks were killed and the weather sides of trees were stripped of their bark. As the sun set the cold became very intense.

On February 9, 1825, at 7 P.M., a fall of very large hailstones occurred, accompanied by a violent wind. At 11 P.M. a second storm of great violence occurred, and at 3 A.M. hail fell for the third time. The wind during the night blew from every point of the compass. About 6 A.M. a fourth hailstorm occurred, and a bungalow was struck by lightning.

On the 5th of March, 1827, a hailstorm broke with most extraordinary violence near Kotah, coming on with a furious north-wester. Six persons were killed by the hail, and vast numbers of cattle, sheep, goats, and birds.

On April 26, 1829, at Calcutta, a very severe thunderstorm occurred, and hail fell, measuring 2½ by 1½ inches, and ¾ inch thick. Many of the stones were square and angular, like pieces of stone broken off from a mass of rock. Dark clouds seemed to be coming from north-west against the south-east wind.

In April, 1829, at Serampore, hailstones as large as a hen's egg were picked up, composed of successive layers, and having a white nucleus.

On April 10, 1831, at Kamptee, hailstones of 10 to 12 inches in circumference fell; few or none were smaller than a hen's egg. Five persons were killed, and many ducks and geese.

On May 5, 1833, at Allahabad, a hailstone was measured of 10 inches in circumference. Its weight was 6¾ oz. troy. These figures were verified and signed by two gentlemen in the Civil Service. At Chunar during the same storm, a hailstone was measured of 11½ inches, and two men were killed.

On April 18, 1834, at Pubna, a hailstone was found to be 12 inches in circumference.

On April 7, 1847, at Belgaum, the temperature before a hailstorm was 90°; after the storm 70°.

At Poona, on May 22, 1847, in a conflict of winds, a very heavy hailstorm occurred. The temperature fell from 90° to 72°. The mass of clouds after passing over had the appearance of a funnel, from the lower and central part of which a dark pillar of cloud connected it with the earth. The mountain of Singhur, more than 4000 feet high, was too low to have formed even the base of the vast column reaching upwards to join the elevated body of cloud from which the rain and hail were falling.

On January 14, 1849, at Deesa, a violent thunder and hailstorm was followed by intensely cold and clear weather.

On November 24, 1849, at Indore, a violent storm of wind and hail was followed by uninterrupted cold weather, the thermometer falling to 34°. The palace was struck by lightning. A marked decrease of temperature took place at Broach, where there was no hailstorm, but a strong cold wind blew about 2 o'clock, after an oppressive morning.

On December 1, 1849, at and near Delhi, there was a thunderstorm, rain, and hail. The reporter observes: "Since that day the weather has been very cold."

29. REMARKABLE HAILSTORMS IN INDIA, 1851–55.*

With regard to the distribution of hailstorms in different months, it was found that the number in each month during the period was as follows:—

January	5	July	2
February	20	August	0
March	31	September	2
April	34	October	3
May	17	November	4
June	4	December	5

The distribution during the 24 hours was as follows:—

About 3 or 4 P.M.	10	About 2 P.M.	2
At 4 P.M.	1	About 8 P.M.	1
At sunset	4	About 9 A.M.	1
About 11 A.M. or noon	5	After dark	3

The number occurring during the afternoon was thus about three times as large as the number occurring during the morning. It is a common thing for hailstorms to occur in pairs or threes at different places at the same time. Their favourite locality is the damp tepid air of the Delta of the Ganges, and they are common on the west shore of the Bay of Bengal, along the shores of Cutch and Scinde, and in the Ghauts and Deccan at or above a height of 1500 feet. From Surat south to Ceylon hail is almost unknown. The form of hailstones is that of (1) pure crystalline masses, globular or lenticular, transparent, but coated with white ice; (2) the same, but beautifully stellate; (3) nearly globular masses, with concentric coats or layers.

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* 'Transactions Bombay Geographical Society.'

30. HAILSTORM AT CALCUTTA, MARCH, 29, 1864.

Mr. Blanford observes* that—“ In tropical climates, where the temperature at a considerable height from the earth is much above the freezing point, and where, nevertheless, some of the largest recorded hailstones have fallen, the stones must attain their maximum dimensions in the first portion of their fall, and during some subsequent seconds must be subject to the liquefying influence of the lower strata.”

The storm commenced about a quarter to 6 in the afternoon, the wind being from south-east. The clouds, a thick mass of nimbus, approached or formed from the north-west, but appeared to be stationary during the latter part of the storm. Lightning was frequent, and thunder continuous. The hailstorm with rain lasted half an hour. The hailstones had all a more or less oblate or discoid form, some being rudely elliptical in section, while others, and especially the larger, were irregular discs. The exterior was extremely irregular, resembling the extremities of a mass of crystals. The interior was formed by alternating opaque concentric bands (in one case seven), separated by rings of less opacity, and the outer portion consisted of transparent ice containing numerous air-bubbles. The arrangement of the air-bubbles was irregularly radiate. Many of the discoid stones exhibited deep depressions, almost amounting to holes, in their axis. Some stones had transparent, others opaque, nuclei. "Hail," remarks Sir J. Herschel, "seems always to depend on the sudden introduction of an extremely cold current of air into the bosom of a quiescent, nearly saturated mass." The air was very near saturation in this case. The collision of a cold northerly current with the south-east wind may have caused a sudden rise of both into the higher regions of the atmosphere, and if this were very rapid, the reduction in temperature owing to the expansion of the heated air, aided by the cooling influence of the northerly current, might cause hail. The barometric reading indicated such an upward current. "The concentric zones indicate so many atmospheric strata of condensation, and it is probable that they consist of radiating snow spicules, i. e. ice condensed from vapour below the freezing point, and crystallising on a solid nucleus, instead of forming free flakes. In this view each clear zone represents a portion of the stone formed in an atmosphere above the freezing point and subsequently frozen, while each opaque zone represents that contributed by an atmosphere below 32°."

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* Note by H. F. Blanford, 1864.

31. TEMPERATURE AFTER HAILSTORMS.*

"In India, hailstones only fall during the warmest diurnal period, and after their descent the air is exceedingly cold." Extensive observations in recent years, however, have shown that hailstorms are not unknown during the night, and that the temperature does not always fall greatly after hail.

32. HAILSTORM AT SEA, SOUTH ATLANTIC.

On January 14, 1860,† about 300 miles south of the Cape of Good Hope, there was a heavy squall with rain at 10 A.M., and the wind shifted suddenly from east to north. Vivid flashes of lightning followed, and a shower of ice in irregular pieces fell for three minutes. The weight of the pieces was from 3½ to 5 ozs., and a quarter of an hour after the storm, one would just go into an ordinary tumbler. A very thick glass cover of one of the compasses was broken, and some persons were knocked down. The air was close and

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[*] Thomson's 'Introduction to Meteorology.'

[†] Phil. Mag., August 1860.

heavy, the barometer and thermometer pretty steady. The temperature was 70°; the barometer at 8 A.M. 29·82, at 10 A.M. (time of squall) 29·86, at 1 P.M. 29·76 falling. In the morning the wind had been east, in the following night it was north-west, and on the following day west-south-west.

33. HAILSTORM IN NATAL.*

The morning of April 17, 1874, was fine, but about 12.30 P.M. the sky became clouded, and soon large hailstones fell "few and far between." A heavy hailstorm ensued, and was at its height at 2.20 P.M. A light misty rain accompanied the hail. There was no thunder and lightning during the first part of the storm, but several flashes and peals of thunder towards the end. Hailstones passed through corrugated iron roofs as if they had been made of paper. Some of them weighed more than 1½ lbs." Most of the stones were white spheroidal masses, obviously composed of a number of smaller masses of similar character united together, and with hollow depressions upon the surface. When these spheroidal masses were examined in section, it appeared that they were made up of three or four concentric layers of ice, arranged like the coats of an onion, and alternately dark and white. Other stones, less symmetrical in form, had the surface studded over with massive, but irregularly-shaped, crystals of ice. The hailstones, according to Mr. Dunn, were on an average from 1½ to 2 inches in diameter, of regular spherical form, with nucleus of white snow and envelope of hard transparent ice. Some had layers or zones alternately white and transparent. "The irregular masses were formed of a nucleus generally longer in one direction than the others, from 2 to 4 inches in diameter, and with stalactites projecting all over, each one about the thickness of a little finger, and presenting, when broken across, an agate-like structure, as though built up by aggregation. Three were found to be over 8 ozs., two over 6 ozs., and one over 4 ozs. in weight.

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* 'Quarterly Journal of the Meteorological Society,' October 1874: Notes on a Remarkable Hailstorm at Pietermaritzburg, Natal, by the Rev. Digges la Touche; and an account by Mr. Dunn.

34. Thunder and Hailstorms in Natal.*

"The entire stretch of the colonial territory is simply the bevelled rim of the great tableland of Africa, by which the vast central mass subsides suddenly, from an elevation exceeding 6000 feet, to the sea. The general breadth of this sloping rim varies, in the situation of Natal, from 120 to 160 miles; but in the case of the colony, the gradient of the land is made even more severe than this would imply, by the fact that there issues from the inland mountain-frontier a scarcely subordinate ridge, which crosses the entire central district of the colony as a vast highland tract, that is above 5000 feet high through the greatest part of its extent. . . . Every day the air resting over the slope becomes strongly heated by the intense sunshine so long as the sun returns to its high summer noontide elevation in the sky; the heated air is then drawn upwards along the slope by the superior pressure of the lower and cooler atmosphere, but this lower and cooler atmosphere rests over the sea. . . . A sea-breeze is almost constantly blowing—at least during the hotter portion of the day. . . . The invisible vapour, therefore, condenses into visible mist and cloud, and very soon pours down copiously as rain, with the accompaniment of electrical manifestations developed by the abundant and rapid condensation. . . . More than two-thirds of the thunderstorm rain commenced between the hours of 3 and 7, one-fifth began about 6 in the evening."

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* 'The Rainfall of Natal,' by R. J. Mann.

35. Hail in South Africa, Australia, India, and South Europe.

"In Natal the storm-cloud may often be seen to arise as a small wisp of vapour in the clear sky, hanging over the seaward slopes of the Drakenfeld mountains, which then begins to revolve and enlarge until it is matured into a thunderstorm. Lightning occurs, and the thunderstorm sweeps down from the mountains over the plains."[*] Natal is stated to be subject to severe hailstorms.

At Queenstown, South Africa, on February 18, 1882,[†] a hailstorm occurred in which the hailstones were as large as hen's eggs, weighing 1½ oz. to 2½ ozs. Corrugated iron roofs were pierced. The hail was preceded and accompanied by lightning and thunder.

"M. Despine, who investigated carefully in 1840 the situations which were most liable to hail in Sardinia, came to the conclusion that the direction of high mountain-chains, obviously exerted a strong influence."

In the south of Europe and South Africa hail is common,[‡] in the tropics uncommon. In India it occurs chiefly during the warmest part of the day; the air turns very cold after a hailstorm.

Thunder and Hailstorms in New South Wales.[§] It appears that severe thunder and hailstorms are not very uncommon in New South Wales, especially in the first year after a drought, and in the summer season. In wet years they are neither severe nor numerous.

In February 1847, in New South Wales, hail fell of various forms, which were compared with eggs and oranges, and some of the stones were said to be 14 inches in circumference.*

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[*] 'Science for All,' by Dr. R. J. Mann. [†] Kämtz's 'Meteorology.'

[‡] Symon's Met. Mag., 1882.

[§] See 'Paper read before the Royal Society of New South Wales,' by H. C. Russell.

36. HAIL IN CUBA.

M. Ardouin of St. Domingo has stated† that hail often falls in Haiti in the mountains. At elevations of 800 to 1200 toises (say 6000 feet) hail sometimes destroys the flowers or fruit of the coffee-plant. M. Ardouin states that about 4 P.M. on March 22, 1820, he witnessed a hailstorm at Port-au-Prince, accompanied by a very violent wind, lasting about half-an-hour. Some hailstones of the size of a walnut were picked up. M. Poey shows, in tabular form, that hailstones are most common in March and April, next in August, May and June.

37. HAIL AND SNOW IN THE ARCTIC REGIONS.‡

Hail is almost or quite unknown in the Arctic Regions. "The only substance resembling hail which falls in the frigid zone consists of a white porous spherical concretion, of a light and snowy texture." Thunderstorms may be said to be about equally rare, for Parry during 28 months in the Arctic seas, including three summers, only observed one thunderstorm, which was a small one, about lat. 70°, in Baffin's Bay. "When the temperature is near freezing point, and much snow falls, it frequently consists of large irregular flakes, such as are common in Britain; sometimes it exhibits small granular or large rough white concretions, at others it consists of white spicules, or flakes composed of coarse spiculæ, or rude stellated crystals, formed of visible grains. But in severe frosts, *though the sky appears perfectly clear*, smaller flakes of snow, of the most regular and beautiful forms, are always seen floating in the air and sparkling in the sun-beams, and the snow which falls in general is of the most elegant texture and appearance. The regular hexagon occurs in moderate as well as in the *lowest* temperatures, but it becomes more delicate and thin, and diminishes in size, as the cold increases (about 14° F.). Fine spiculæ or six-sided prisms appear with a temperature about 28° F., and the coarser forms when near the freezing point. Sometimes a number of different figures appear in the same storm or shower. In low temperatures, the greatest proportion of crystals which fall are probably perfect geometrical figures." Scoresby gives 96 specimens of snow-crystals.*

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* Kämtz's 'Meteorology.'

† 'Mémoire sur la fréquence des chutes de Grêle à l'Île de Cuba,' par M. André Poey.

‡ 'Account of the Arctic Regions,' Scoresby.

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* See also 'Observations at Griffith Island' in 'Meteorology of the Arctic Regions'; published by the Meteorological Council.

38. SNOW-CRYSTALS ON THE ALPS.

Professor Tyndall [*] has described as follows a shower of snow on the top of Monte Rosa: "All of the flakes were six-leaved; some of the leaves threw out lateral ribs like ferns; some were rounded, others arrowy and serrated; some were close, others reticulated, but there was no deviation from the six-leaved type. . . . Had a spirit of the mountain inquired my choice—the view or the frozen flowers—I should have hesitated before giving up that exquisite vegetation."

M. Dollfus, who spent a winter on the Theodule Pass, at 10,280 French feet in altitude, relates [†] that in *winter* the snow was generally in the form of a fine dust, like that of the Arctic regions, and that the first fall of large flakes occurred on May 29.

39. HAIL ON HIGH MOUNTAINS.[‡]

"De Saussure, during his stay of 13 days on the Col du Géant, at the height of 3428 metres, was struck with the frequency of hail and sleet, which occurred eleven times. The guide Balmat experienced a shower of hail in the night spent on the summit of Mont Blanc. Zurnstein, in his ascent of Monte Rosa, June 12, 1822, observed hail at the height of 4550 metres. Welden states that rain in the plains signifies hail and sleet in the mountains. In Switzerland hail frequently falls in the mountains and on the plains, but seldom in the valleys."

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[*] 'The Glaciers of the Alps,' 1860.

[†] See Hartwig's 'Aerial World.'

[‡] Kämtz's 'Meteorology.'

De Saussure * found that heavy hail falls more frequently on the plains at some little distance from the mountains than close to or among them.

Hail on the Andes.† — At a height of about 15,000 feet on Cotopaxi, Whymper experienced frequent storms of hail. Flashes of lightning were frequent and close, conveying the impression that the air was full of electricity. At this height the temperature was 28° F. Cumulus was seen in the distance at about 23,000 feet high. Near the top of Cotopaxi the temperature was 13° F. On Chimborazo, at 16,664 feet, the temperature at 11 A.M. on January 9 was 72°·5, and at night on January 5 only 17°. The tops of mountains above 13,000 or 14,000 feet were usually clear in the morning, but there were clouds below. By 8 A.M. clouds commenced to form on the eastern side of the mountain, and gradually extended upwards. There were thunderstorms on the south side every day from December 28 to January 12 inclusive—some extremely violent. These seldom occurred before mid-day. Snow fell around the travellers every day to a depth of about 3 inches. It was commonly wet, and in small flakes; dry, powdery snow did not occur. Hail fell, but not much or large.

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* 'Voyage dans les Alpes.' † Whymper's 'Andes,' 1892.

On the summit of Corazon, at about 15,000 feet, rain, sleet, hail or snow fell. On Illiniza there were thunder, snow and hailstorms. On the summit of Sinchulagua, near 16,000 feet, there was a violent hailstorm, the hail consisting of balls half an inch in diameter, which actually broke fragments of rock from the higher ledges; then snow began to form, at first mixed with the hail, afterwards in large flakes; thunder and lightning increased, the whole air seemed to be saturated with electricity, and ice axes hissed ominously.

On the summit of Antisana there was a fierce hailstorm, followed by heavy snow. At 19,000 feet the highest temperature was 60°, the lowest 44°. At 13,000 feet the highest temperature was 49°.

On Cotocachi, at 14,000 feet there was the usual succession of rain, hail and sleet.

On Chimborazo, at 16,700 feet the temperature was 26°·5 F.; at 9039 feet it was 50° F. On the summit of Chimborazo on another occasion it was 15° F. at 2 P.M., while at Riobamba, down below, it was 54°·72 F. This difference gives a rate of 1° F. for 288 feet. In two hours, on one occasion, there was a drop of at least 35°, from 50° to 15°, caused by the clouds of volcanic dust interrupting the rays of the sun. Upon a number of occasions abrupt transitions of temperature occurred at the high camps while the travellers were ascending.

In speaking of the Andes, Humboldt * describes them as stormy, and says that they are visited by terrific hailstorms, the hailstones being not only flattened by rotation, but run together into thin plates of ice.

HAIL ON PIKE'S PEAK.†

May 14, 1874.—" At 10 A.M. the wind veered to the north-west. At 12 it hailed very heavily, the stones being as large as peas, and of soft white snow throughout."

May 24.—" A heavy thunderstorm passed slowly over the peak from 10 A.M. to 3 P.M. Large sparks passed constantly through the lightning-arrester, while a strange crackling of the snow could be heard at times."

May 29.—A violent thunderstorm occurred on this day at 6 P.M. "The noise of thunder-claps was almost drowned by the rattling of the almost indescribably heavy showers of sleet which followed each discharge. The storm seemed to surround the peak in all directions. . . . The rattling of torrents of sleet, mingled with the incessant roll of thunder, the blinding flashes and loud reports in the rooms, were enough to make the stoutest heart quail. . . . Sleet was succeeded by heavy snow."

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* See Proc. Met. Soc., 1866.

† 'Annals of the Astronomical Observatory of Harvard College,' Edward C. Pickering, Director. Vol. xxii. Meteorological Observations made on the summit of Pike's Peak, Colorado, lat. 38° 50′ N., long. 105° 2′ W.; height, 14,134 feet; (the altitude of Pike's Peak above the surrounding country is about 8000 feet); January 1874 to June 1888; under the direction of the Chief Signal Officer, U.S. Army.

June 2.—" At 2.30 P.M. storm-clouds advanced, with a violent whirling motion, from a point south and east of the summit, and close over the mountains surrounding the peak in that direction. The vortex crept slowly along the eastern slope of the peak, and the clouds were hurrying towards it from all directions. Over the summit they moved from the west and north-west, south of the summit from south-west and south-east, and north of it from north-east and north. The whole mass revolved against the sun. At the same time the clouds had a strong downward tendency, while from the centre of the vortex dense whitish masses of vapours poured upward like volumes of smoke. Thunder and lightning accompanied the storm, and heavy showers of sleet fell on the summit. The wind during and after the storm blew steadily and briskly from the west."

July 1.—" A heavy thunderstorm passed over the summit from south-west to south-east between noon and 2 P.M., and sleet of remarkable size fell during its progress. The stones were of hard snow without nucleus, and many of them as large as pigeons' eggs. Violent cloud-whirls were observed before the beginning of the sleet. Visitors caught in the storm near the summit stated that they all experienced peculiar burning sensations on face and hands, and heard a hissing sound proceeding from their hair."

July 21.—"Heavy hail began at 2.5 P.M., the stones varying in size, and composed mostly of solid transparent ice. One of the heaviest thunderstorms of the season advanced upon the peak from the north-west, and appeared to remain stationary on the summit. The hail came down in continuous torrents until 7.30 P.M. The lightning and simultaneous thunder were terrific. The fallen hail crackled constantly with electricity."

May 15, 1875.—Hail. The cloud, which rested on the peak, seemed illumined by the electric discharges.

May 29.—Hail, with electricity. The observer notes that in all hailstorms the fall of hail entirely ceases for about half a minute following a heavy electric discharge, and that the hail-fall is considerably heavier for some little time following the discharge than before. Some of the stones collected were as large as peas, almost round, and formed of hardened snow. The observer failed to note the whirling motion in front of the cloud as described by Professor Loomis.

July 5.—Hail from 11 A.M. to 1.15 P.M.

Terrible electric storm. Constant stream of flame from lightning-arrester.

August 10.—From 3 to 8 P.M. the heaviest hailstorm the observer ever saw. The stones averaged half-an-inch in diameter, while those fully 2 inches in diameter were not rare. On being broken they presented a stratified structure, with a centre of clear ice, the outer covering being of soft snow.

June 15, 1876.—Hailstones of an inch and less in diameter. They had a decided nucleus, around which were concentric formations. The nucleus was of hard white ice, while the concentric rings were of transparent ice, either solid or spongy, except the outer one which was of snow. Thunder and lightning accompanied the storm.

"The singing noise [a phenomenon of the same nature as St. Elmo's fire] is never heard except when the atmosphere is very damp, and rain, hail or snow is falling."

May 29, 1878.—"It is remarkable that whenever a heavy thunderstorm develops on the eastern plains, the prevailing west wind rises to a gale, blowing towards it."

June 29.—"During the afternoon a most wonderful storm was witnessed in South Park, about 50 miles away. Small fragmentary clouds coming from the Snowy Range assembled rapidly in dark masses, which assumed the shape of an inverted cone. The cone once formed, small clouds could be seen drifting rapidly in all directions from the centre. At 4 P.M. the inverted cone, having been nearly stationary for about 40 minutes, suddenly began to rise like an immense balloon, and, upon attaining a considerable height, gradually lost its form and soon after dissipated. A white spot of 10 or 15 acres showed that it had been a tremendous hailspout, the hail not disappearing till nearly sunset."

June 24, 1883.—Some of the larger hail was fully 1¼ inch in diameter, and of a light porous nature, in shape resembling a balloon.

Mr. Greeley, the chief signal officer, says that the electrical storms for which Pike's Peak is celebrated only occur when the air is moist; the most favourable condition is when a light, soft snow is falling. When the hands are held up sparks emanate from the tips of the fingers. Each flake of snow as it alights on a mule's back gives a spark like a fire-bug. With considerable wind the anemometer cups look like a circle of fire.

41. BALLOON VOYAGE IN A THUNDERSTORM.

Mr. Wise observed that "the upper surface of cloud is bulged upward and outward . . . and has the resemblance of a vast sea of snow boiling and upheaving from internal convulsion. Immediately above the storm the air is not so cold as in a place where there is no cloud and no storm beneath. . . . A side view of the storm, a mile or two off, presents the shape of an hour-glass, and the picture of a waterspout also gives a good outline of its shape." On the 17th of June, 1843, Mr. Wise was carried into a local tornado, which he afterwards described in a letter to a newspaper.* "This storm originated nearly over the town of Carlisle, Pennsylvania, on the 17th of June, 1843. I entered it just as it was forming. The nucleous cloud was just spreading out as I entered the vortex unsuspectingly. I was hurled into it so quickly that I had no opportunity of viewing the surroundings outside, and must therefore confine this relation to its internal action. On entering it, the motions of the air swung the balloon to and fro, as around in a circle, and a dismal howling noise accompanied the unpleasant and sickening motion; and in a few minutes thereafter was heard the falling of heavy rain below, resembling in sound a cataract. The colour of the cloud internally was of a milky hue, somewhat like a dense body of steam in the open air, and the cold was so sharp that my beard became bushy with hoar-frost. As there were no electrical explosions in this storm during my incarceration, it might have been borne comfortably enough, but for the sea-sickness occasioned by the agitated air-storm. Still, I could hear and see, and even smell, everything close by and around. Little pellets of snow (with an icy nucleus when broken) were pattering profusely around me in promiscuous and confused disorder; and slight blasts of wind seemed occasionally to penetrate this cloud laterally, notwithstanding there was an upmoving column of wind all the while. This upmoving stream would carry the balloon up to a point in the upper cloud, where its force was expended by the outspreading of its vapour, whence the balloon would be thrown outward, fall down some distance, then be drawn into the vortex, again to be carried upward to perform the same revolution, until I had gone through the cold furnace seven or eight times."

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* *New York Tribune*, February 1857. See Ferrel's 'Treatise on the Winds.' This account, like others by the same aeronaut, is wanting in scientific observation.

42. STATISTICS OF HAILSTORMS IN WÜRTEMBERG.*

"K. von Riecke has collected and studied the statistics of hailstorms and resulting damages in Würtemberg, during the thirty years from 1828 to 1857, the work being a continuation of that previously published by Camerers. He gives interesting quotations from early chronicles dating back a thousand years, which have, we understand, been reprinted in previous 'Jahrbücher,' published by the Würtemberg Statistical Bureau. The average number of hailstorms is 14·8 per year during the first half of the period investigated by Riecke, but only twelve in the latter half of that period. The years of most frequent hailstorms were—1852 (? 26), 1847 (24), 1834 (23), 1835 (23), 1873 (22), 1839 (20). The average area covered by the hail that fell from these storms is 2525 morgens, or 796 hectares, or 1967 acres.

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* Extract from 'Physics of the Globe,' by Cleveland Abbe, pp. 181–2.

By summing up the areas covered by hail, it is found that the years of maximum area were, in regular order—1873, 1872, 1853, 1852, 1869, 1856, 1830, 1846 and 1832; and the years of minimum area were—1838, 1851, 1858, 1844, 1857, 1874, 1835, 1848, 1842 and 1840. A strong indication is given of an increase in the intensity of thunderstorms. Besides numerous interesting historical notices dating back to the year 855, Riecke gives detailed tables of the hailstorms and of the property destroyed during the last fifty years."

43. GEOGRAPHICAL DISTRIBUTION OF HAIL.*

From a statistical inquiry by Prof. H. Fritz, it appears that pellets of snow fall in all latitudes and at all heights; hail is confined to middle latitudes, and is rare in high latitudes and tropical lowlands. Hail occurs when the vapour of the atmosphere is precipitated in excessive quantity, and is proportional to this excess. The higher the latitude, the less the fall of hail and the greater the fall of graupel. Since the heaviest hailstorms rarely occur in tropical lowlands, the regions of the most frequent and destructive hailstorms are in the middle latitudes. In high latitudes, and on high table-lands, the height above the earth of the atmospheric strata with temperature below zero is small, and therefore more graupel and snow fall than hail; while in middle and low latitudes this height, especially in summer, is sufficient to allow of the formation of large hailstones. The maximum of hail-fall takes place between latitudes 40° and 60.° Atmospheric currents and mountains considerably affect the distribution of hail.

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* Petermann's 'Mittheilungen,' November 1876.

44. OBSERVATIONS ON A SMALL WHIRLWIND.*

M. Raoul Pictet made some observations on whirlwinds in Egypt on the 2nd of June, 1873, which give a fair idea of the persistent action which may be maintained by a whirling column of heated air on a small scale. The whirls took place on a mound of sand about two miles north-east of Cairo. At 10.5 A.M. the average temperature of thermometers lightly buried at less than a centimetre in the sand was 84° C. At this time there were the beginnings of an apparent whirl, and at 10.30 it was formed, showing an opaque column of sand about 20 metres high. The temperature of the air at 10.40 was 34°·5 C. Feathers and paper were carried up. At 11 A.M. the height was from 400 to 500 metres, and the base, of which the diameter was 2 metres, was about 2 metres above the ground. The speed of rotation at the circumference near the ground was about 10 to 12 metres per second. At 11.50 there was a light breeze from the south, and the whirl was moving on. No electric effect was seen on the electrometer. At noon the height was estimated at 1000 metres, and the paper was *still* whirling at a great height, whenever seen, but the column was opaque. In the whirl the temperature was very high. The appearances lasted till 3 o'clock.

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* 'Contributions à l'Étude de la Grêle,' Prof. Daniel Colladon. Geneva.

CHAPTER II.

OBSERVATIONS OF TEMPERATURE, CLOUDS AND WINDS AT GREAT ALTITUDES.

In the accounts of hailstorms and hail at high stations given in Chapter I. it is very evident that hail is frequently, in fact generally, formed at great altitudes. Some of the conditions which prevail in the upper air at ordinary times will be gathered from the following notes made by several good observers, on mountains and in balloons.

45. Balloon Ascents.*

On December 1, 1783, the temperature on the earth was 47°; at 9000 feet, 21°.

In April 1784 the temperature at 13,000 feet was 25°.

On July 22, 1784, in a cloud the temperature was 50°, and higher it was 26°.

In Gay Lussac's ascent of September 16, 1804, at a height of 22,977 feet clouds were seen apparently at an immeasurable height overhead. The temperature was 17°·1.

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* 'Travels in the Air,' by James Glaisher, F.R.S. 'The Aerial World,' Hartwig.

On September 15, 1805, the temperature on the earth was 82°; at 23,000 feet, 15°.

On July 27, 1850, Barral and Bixio left the earth at about 4 P.M., after heavy rain. They entered a cloud at about 7000 or 8000 feet high, which proved to be fully 15,000 feet in thickness. At the highest point attained, about 23,000 feet, in thin clouds, a mock sun was seen. At 19,685 feet in the ascent, the temperature was 17°·1;* at 23,000 feet only – 38°·2, and the clothes of the observers were covered with fine needles of ice.

On September 5, 1862, the temperature on the ground was 59°·5; at 15,600 feet, 18°; at 20,000 feet, 8°; and at 5 miles, or 26,000 feet, – 5°. At about 36,000 or 37,000 feet a very delicate minimum thermometer read, – 11°·9.

On July 17, 1862, the temperature on the earth was 59°; at 10,000 feet, 26°; at 15,000 feet, 31°; at 19,500 feet, 42°; but on descent a little below this height the temperature fell with extraordinary rapidity to 16°.

On March 31, 1863, the temperature on the ground was 50°; at 15,300 feet, 14°; at 23,000 feet, 0°; and descending below 15,300 feet, 7°; on the ground on descent, 42°. Up to 10,300 feet the wind was east; between 10,300 and 15,400 feet, west; about 15,400 feet, north-east; higher still, south-west; and from 20,600 to 23,000 feet, west.

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* Some of these figures are quite incorrect, see p. 81.

On April 18, 1863, the temperature on the ground was 61°; at 20,000 feet, 10°·5; at 22,000 feet, 16°·5; at 11,000 feet, 18°. The wind on the ground was north-east; at a moderate height, north.

On June 26, 1863, the temperature on the ground was 65°; at 19,000 feet, 21°·8; at 5000 feet, 39°2; and on the ground on descent, 66°·5.

On July 11, 1863, the temperature near the ground was 75°; at 5000 to 6000 feet, 53°. The wind was east on the ground, and north at a moderate height—2600 feet. The humidity of the air on passing from the east to the north wind increased greatly.

On July 26, 1863, clouds or dry and wet fogs were passed through up to 19,600 feet from 10,000 feet; from about 21,000 to 22,000 feet nimbi were passed through. At 23,000 feet the balloon was above these clouds, but dark clouds of a stratus character and cirri were seen much higher. Rain fell at 15,000 feet, snow in fine crystals for 4000 feet between 14,000 and 10,000 feet. Proof was thus obtained of the possibility of rain falling at this season above snow, at a great altitude. The temperature at starting was 65°; on descent, 66°; at the highest point, 18°.

On January 12, 1864, on the ground, wind was south-east; at 1300 feet, strong south-west; at 4000 feet, south; at 8000 feet, south-south-west; about 10,000 feet, south-south-east.

On April 6, 1864, the wind on the ground was south-east; and at about 9000 feet, north-west. Temperature was 45°·5 near the ground, 33° at 4500 feet, 40° at 7500 feet, 34° at 8800 feet, 37° at 11,000 feet.

On June 13, 1864, the temperature was 62° near the ground, 51°·5 at 3000 feet, 53°·2 at 1800 feet, and near the earth about 53°.

On May 29, 1866, the temperature on the surface was 58°; at 6200 feet, 29°·5; at 3400 feet humidity was 57°; at 4800 feet the air was saturated. Wind on the ground, north by east; above 2000 feet, north by west; at 5100 feet, nearly calm.

On June 10, 1867, the air at the surface was calm; the wind at a low elevation, north-east; higher, south-south-west; and higher still, north.

On June 26, 1869, the wind on the surface was north-east; at 10,000 feet, south-west.

Mr. James Glaisher, F.R.S., on Observations made in Balloons.[*]—On June 17, 1862, in descending, the balloon passed through a cloud 8000 feet thick, from 12,000 feet to 4000 feet above the earth. On September 5, at a height of 3 miles, the temperature was 18°; at 4 miles, 8°·5, with dewpoint 6°; at 5 miles, 5°, with dewpoint 36° below zero F. At about 37,000 feet [the highest altitude ever attained by man] the minimum thermometer was 12° below zero F. "In no instance has the temperature decreased uniformly with height. . . .

[*] Proc. Brit. Met. Soc., Nov. 1862.

At the extreme high stations the difference between the air temperature and dew-point was wonderfully great, indicating an extraordinary degree of dryness and an almost entire absence of aqueous vapour." Yet it is interesting to note that cirrus was seen far above this dry region, showing the presence of filaments at least of somewhat vaporous air, out of which the vapour was condensed to ice crystals by intense cold and free radiation. Mr. Glaisher states * that at 4 miles high he had constantly to break ice to get water for the wet-bulb thermometer; surface ice formed *instantly*.

Müller gives the following particulars of the ascent of July 27, 1850, by Barral and Bixio. Temperature at 2300 Paris feet, 16° C.; at 11,250, 0·5°; at 15,360, −7°; at 19,530, −15°; at 21,060, −39°. On emerging from the clouds (at about 20,000 feet apparently), fell to −23°·8. Ice-needles only formed at −10°; the balloon must have passed through 7000 feet of ice-cold water particles.

Recent experiments with small balloons showed that a very great cold prevails at altitudes which are reached by the highest clouds.† On March 21, 1893, the registering apparatus was found to have recorded a temperature of − 51° C., = − 60 F., at a height of about 45,500 feet. The temperature at Vaugirard at the time was 17° C.

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* Proc. Brit. Met. Soc., March 1863.

† 'Comptes Rendus,' 1893; 'L'Aerophile,' 1893.

CHAPTER III.

ELECTRICITY AND HAIL.

46. Various Observations on Atmospheric Electricity.

The following observations and opinions regarding the connection of electricity with the occurrence and formation of hail are instructive.

According to the observations of Muncke, single flashes of lightning are not so common at the beginning of a hailstorm as a continual electric illumination, and an uninterrupted rolling of thunder. Six inches is about the maximum depth of hail in a single fall in Germany.

The origin of atmospheric electricity is generally attributed to evaporation, by which the evaporated water and the water surface take electricity of opposite signs. "Solids and liquids cannot be charged throughout their substance; if charged at all the electricity is upon their surface. But gases and vapours, being composed of myriads of separate particles, can receive a bodily charge. The air in a room in which an electric machine is worked is found afterwards to be charged. The clouds are usually charged more or less with electricity.

The minute particles of water floating in the air, being better conductors than the air itself, become more highly charged. As they fall by gravitation and unite together, the strength of their charges increases. Suppose eight small drops to join into one. That one will have eight times the quantity of electricity distributed over the surface of a single sphere of twice the radius of the original drops, and its electrical potential will consequently be four times as great. Now a mass of cloud may consist of such charged spheroids, and its potential may gradually rise, therefore, by the coalescence of the drops, and the electrification of the lower surface of the cloud will become greater and greater, the surface of the earth beneath acting as a condensing plate, and becoming inductively charged with the opposite kind of electrification."

"The main result of observations on atmospheric electricity made by Quetelet and by Sir W. Thomson, was that the air above the surface of the earth is usually, during fine weather, positively electrified, or at least that it is positive with respect to the earth's surface, which is relatively negative. . . . The lower air is, when dry, a non-conductor. The upper stratum is believed to be charged with positive electricity, while the earth's surface is itself negatively charged, the stratum of denser air between acting like the glass of a Leyden jar in keeping the opposite charges separate. . . . Sir W.

Thomson found the potential in the Island of Arran to increase from 23 to 46 volts for a rise of one foot in level; but the difference of potential was sometimes eight or ten times as much for the same difference of level, and changed rapidly as the east wind blew masses of cloud charged with positive or negative electricity across the sky. Joule and Thomson, at Aberdeen, found the rise of potential to be equal to 40 volts per foot. . . . In broken weather and during rain it is more often negative than positive, and exhibits great fluctuations." *

Luke Howard found† that the positive electricity common to fair weather often yields to a negative state before rain. In general the first rain after a barometric depression is negative. Forty cases per cent. of rain show negative, though the air is positive before and after. Snow and hail unmixed with rain are positive almost without exception.

Schübler found that in cloudy weather the air is still positive; that during storms, or when it rains or snows, it is sometimes positive and sometimes negative, and much stronger than in fine weather. The days of positive precipitation were seventy-one, of negative sixty-nine.

Arago observed eleven, De Saussure fourteen

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* 'Electricity and Magnetism,' Silvanus Thomson.

† Howard's 'Climate of London,' and Daniell's 'Meteorology,' vol. ii. p. 376.

changes of electric sign during storms. De Saussure found electricity strongest in high isolated situations.

Daniell observes: "As a proof of electrical action, it is sufficient to follow for a short time the movements of an atmospherical electrometer on the approach of hail, when the electricity will not only be found frequently to change in intensity, but also to pass from plus to minus, and *vice versâ*, ten or twelve times a minute. Thunder and lightning are, moreover, very common accompaniments of a hailstorm."

Mr. Walker states * "When the thundercloud draws near, the pith balls suspended from the conductor open wide, with either plus or minus electricity, and when the edge of the cloud is perpendicular to the exploring wire, a slow succession of discharges takes place between the brass ball of the conductor and one of equal size carefully connected with the nearest spot of moist ground. . . . After a certain number of explosions, say of minus electricity, which at first may be nine or ten a minute, a cessation occurs of some seconds or minutes, as the case may be, when about an equal number of explosions of plus electricity takes place of similar force to the former, indicating the passage of two oppositely and equally electrified zones of the cloud; then follows a second zone of minus electricity, occasioning several more discharges in a minute than from either of the first pair of zones; which rate of increase appears to vary according to the size and power of the cloud. Then occurs another cessation, followed by an equally powerful series of discharges of plus electricity, indicating the passage of a second pair of zones; these in like manner are rapidly followed by others, fearfully increasing the rapidity of the discharges, *when a regular stream commences,* interrupted only by the changes into the opposite electricities. . . . When the centre of the cloud is vertical to the wire, the greatest effect consequently takes place. . . . Sometimes, a little previous to the storm, the gold leaves connected with the conductor will for many hours open and shut rapidly, as if they were panting, evidently showing a great electrical disturbance."

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* Kämtz's 'Meteorology,' Notes by C. Walker, p. 578.

With regard to the electrical condition of a cloud-mass, Faraday asks us to "suppose a thin uncharged metallic globe, two or three feet in diameter, insulated in the middle of a chamber; and then suppose the space within this globe occupied by myriads of little vesicles or particles charged alike with electricity, or differently, but each insulated from its neighbour and the globe; their inductive power would be such that the outside of the globe would be charged by a force equal to the sum of *all* their forces, and any part of this globe (not charged of itself) would give as long and powerful a spark to a body brought near it as if the electricity of all the particles near and distant were on the surface of the globe itself." In the case of a thundercloud "the induction upon the earth will be as strong as if all that portion of force which is directed towards the earth *were* upon that surface, and the state of the earth and its tendency to discharge to the cloud will also be as strong in the former as in the latter case."

In the course of the "Instructions published by the Royal Society" in 1840,* the following remarks are found: "Is this rain a cause or consequence of the electric discharge? Opinion would seem to lean to the latter side, or rather we are not aware that the former has been maintained or even suggested. Yet it is very defensible. In the sudden agglomeration of the many minute and feeble electrified globules into one raindrop, the quantity of electricity is increased in a greater proportion than the surface over which (according to the laws of electric distribution) it is spread. Its tension therefore is increased, and may reach the point when it is capable of separating from the *drop* to seek the surface of the cloud, or of the newly formed descending body of rain, which, under such circumstances, and with respect to electricity of such tension, may be regarded as a conducting medium. Arrived at this surface, the tension, for the same reason, becomes enormous, and a flash escapes."

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* See Kämtz's 'Meteorology,' Notes.

Canton observed that in a thunderstorm the electricity would alternately change from plus to minus five or six times in 30 minutes.* "As the temperature of the vapour decreases, its capacity for electricity lessens, and a portion separates. It is easy to conceive that this electricity accumulates around the individual molecules and prevents the coalescence of the vesicles into drops."

47. St. Elmo's Fire on Ben Nevis.

Jets of St. Elmo's fire occur on Ben Nevis, with blinding showers of snow and hail.† Fifteen cases had occurred in 1888, all in the night-time, and between September and February, but there is reason to believe that it occurs as frequently in the day-time and in summer. In all but one case the temperature was below 32°. The phenomenon is related to certain known meteorological conditions over the British Islands. Shortly before the appearance of the fire there is a distinct veering of the wind. The snow-hail which falls is not flaky but in small cones, hard and dry, with spherical bases. It is always present during the finer displays, and seems to be caused by mixture of currents and rapid condensation.

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* Thomson's 'Meteorology.'

† Proc. Met. Soc. of Scotland, vol. viii.; 'St. Elmo's Fire on Ben Nevis,' Angus Rankin.

48. Experiments in Hailstorms.

In treating of atmospheric electricity, Luke Howard * considers that the fact is proved that a cloud formed in a positive atmosphere acquires therefrom a positive charge, of greater intensity than that of the atmosphere itself. Read † noted, on July 2, 1789, that "near 4 p.m. a very large black cloud passed over the rod, and let fall a little rain mixed with hail, by which the rod became highly electrified negatively. The bell now rang briskly, till a flash of lightning and instant crack of thunder happened, which occasioned a sudden change to positive; then the bell struck up again as brisk as before. On March 21, 1791, some rain fell mixed with snow, which lasted near one hour. During this time the rod was most powerfully electrified positively. I counted seventeen spontaneous explosions, between the brass ball and bell. 5.30 P.M., a second shower of rain, hail, and snow . . . the charge in the rod was as strong as possible, for the fluid streamed between the ball and bell. There were four changes, but all gradual. On April 23 a most awful darkness filled the atmosphere, and some rain fell mixed with hail. The charge now became positive, and for ten minutes was as strong as it possibly could be, for I now counted 172 spontaneous explosions

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* 'The Climate of London,' Luke Howard, vol. i., 1833.

† Phil. Trans., vols. lxxxi., lxxxii.

between the brass ball and the bell. The electricity ended negative." Howard deduced from a tabulation of Read's observations that snow and hail unmixed with rain are positive almost without exception.

49. Electricity and Cold.

Kämtz observes* that "A shower of phosphorescent snow has frequently been seen to fall to the earth, and in this case there is always a strong charge of electricity in the air."

The temperature over Northern India at such moderate heights as 10,000 to 20,000 feet must often be much below the freezing point, and there is thus ample room for the formation of large hail. Abercrombie relates † that a temperature of 21° F. was registered at a height of 11,000 feet on the Himalayas at night.

The same observer states that on Pike's Peak, Colorado, at 14,147 feet, extraordinary electrical phenomena accompany the approach or presence of thunderstorms. "The most startling manifestations are exhibited during slight showers of wet snow which fall in the thundery weather of the summer months. Then every pointed thing emits sparks. During a thunderstorm the hail crackles as it falls. Hair stands on end and electricity escapes with a hissing sound."

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* Kämtz's 'Meteorology,' p. 375.

† Abercrombie's 'Seas and Skies in many Latitudes.'

‡ See also Hooker's 'Himalayan Journals.'

50. Electricity, Rain, Hail, and Snow.

At Kew Observatory, during the years 1845-6-7, of the 10,500 observations, 10,176 showed positive, 364 negative electricity. The earth's surface is always negative.* The negative observations almost all occurred during heavy rain. The electricity of the air increases in intensity with height. The maximum occurs in January. Evaporation from water containing a salt gives off negative electricity to the air. Sir John Herschel considers "that when a great multitude of the molecules of vapour are condensed by cold into a drop or snow crystal, however minute, that drop collects and retains on its surface the whole electricity of the molecules from which it was formed. One thousand particles joined into one have a thousand times the amount of electricity of each one, and that electricity being spread over a relatively smaller surface has a tenfold tension or density. Thus the highly electrical state of fog and clouds is explained."

In a thunderstorm, the condensation of vapour and consequent formation of dense electricity, is rapid, and the electricity does not escape into the air with sufficient rapidity to prevent sudden discharges in the form of flashes of lightning. A flash of lightning has often been stated to be followed immediately by a heavy fall of rain or hail, but we must remember that rain and hail take several minutes to fall from the height at which they are usually formed, so that the lightning is probably the result of two conditions, first the condensation of the cloud particles into large drops, by which the electric tension is increased, and secondly the bridging of the space between clouds and earth by the falling water. Heavy rain often abruptly ceases soon after a flash of lightning, and the sudden cessation would be noted as following the discharge, but may depend upon the previous tension in the cloud. The rain ceases suddenly, and the easy passage to earth being hindered, there is a temporary cessation of lightning. During thunderstorms sudden changes from positive to negative, and negative to positive, take place.

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* Buchan's 'Meteorology,' p. 294.

51. St. Elmo's Fire, etc.

Mr. W. Trail observed a fine example of St. Elmo's fire on the iron spike of a mast before, during, and after the passage of a thundercloud with hail. The flame pointed towards the cloud, and reached a length of 3 feet as it passed over. The phenomenon lasted about four minutes.

De Saussure[*] affirms that the clouds from which hail falls are certainly electric, and Arago[†] that hail is certainly formed in the presence of a great quantity of electricity in the clouds. M. Elie de Beaumont[‡] says of the hailstorm of May, 1838, that a peal of thunder was in every case (three times) followed by a redoubling of the hail, and M. Beudant testifies to the same effect.

In descending from the summit of Mont Blanc Mr. Auldjo[§] encountered a thunderstorm accompanied by thick hail of very large size. "The storm raged with most awful fury; the gusts of wind and pelting showers of hail, accompanied by most vivid lightning, alternating with a perfect calm, were enough to appal the bravest of the party."

Captains Peytier and Hossard[||] were involved in a thunderstorm, at a height of 8215 feet in the Pyrenees, on June 15, 1825, during which their hair stood on end, and a buzzing noise proceeded from their bodies. On August 9, 1826, at 10,124 feet, a storm lasted twenty-four hours, during which it hailed and rained considerably, and the thunder was very frequent.

[*] 'Voyage dans les Alpes,' vol. iv. chap. 38, No. 972.

[†] Novo Cimento; Maggio, 1855; dans une Mémoire de Matteucci.

[‡] 'Comptes Rendus,' tome vi.

[§] 'Narrative of an Ascent to the Summit of Mont Blanc on the 8th and 9th of August, 1827,' by J. Auldjo.

[||] 'The Thunderstorm,' by C. Tomlinson.

Cæsar,* in his book "De Bello Africano," relates that "in the month of February, about the second watch of the night, there suddenly arose a thick cloud, followed by a shower of hail; and the same night the points of the spears belonging to the Fifth Legion seemed to take fire."

Prof. Forbes observed the sound produced by the slow electric discharge called St. Elmo's fire at a height of 9000 feet near Mount Cervin, during a fall of hail. A thundercloud was near, and all the angular stones were hissing like points near a powerful electric machine."

On December 23, 1869, in the Atlantic, the weather was squally, with showers of hail, and luminous brushes of a bluish colour, a foot and a half high, appeared at the points of the conductors on every mast, while the rigging shone with a phosphoric gleam.† These lights made their appearance as soon as the squall reached the ship. They were extremely brilliant whenever the wind blew with all its violence, and diminished whenever it abated. . . . The phenomenon showed itself several times during the night, but only during the gusty weather accompanied with hail.

M. Henri de Saussure,‡ when at the summit of Piz Surley, 10,000 feet high, on June 22, 1867, after a shower of sleet experienced an intense and painful discharge of electricity, resembling St. Elmo's fire, lasting four or five minutes. The sky was grey. The same observer witnessed a similar phenomenon a few years later, at 15,000 feet, on the Nevada de Toluco, in Mexico.

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* 'The Thunderstorm,' by C. Tomlinson.

† 'The Aerial World,' Hartwig.

‡ Ibid.

On July 10, 1863, Mr. Watson * and several other persons had a similar experience on the Col of the Jungfrau. A tremendous thunderclap and a fall of hail were succeeded by the peculiar hissing and boiling sounds of the escape of electricity from their hatchets, stocks, and hands. The snow which followed the hail emitted a sound like that produced by a heavy shower of hail.

52. Experiments on Smoke and Drops.

Admiral Fitzroy † says, "An electrician at a table can cause a little breeze of wind that moves toy-boats in a trough, and can make rain in drops by an electric current through the air we are breathing."

Prof. Oliver Lodge made the following experiments on the electrical disposition of dust and smoke.‡ Two black flasks, one full of hot water the other of cold, were placed in a bell-jar full of

* 'The Aerial World,' Hartwig.

† 'The Weather Book.'

‡ Proc. Roy. Inst., May 28, 1886.

thick white smoke. In about five minutes, the hot one was found nearly free from soot, the cold one covered with soot as with hoar-frost.

An electrified rod, up to one or two hundred volts, produced a barely noticeable effect, but as soon as the potential rose to a few thousand volts, and brush discharge began to be possible, a very violent and remarkable effect began to be noticeable—the dark (dust-free) coat widened enormously and the whole box was rapidly cleared of smoke. If electricity is discharged into any smoke from a point connected with a Voss or Wimshurst machine, the other pole being connected with the ground, a very rapid aggregation of the particles of the smoke takes place; they form in masses or flakes along the lines of force,* and in another instant the jar is clear of smoke; it has all been condensed on the sides and floor of the vessel. A round knob will act instead of a point, but not so quickly. Brush discharge, or anything which electrifies the air itself, is most effectual. Lord Rayleigh's experiment on scattered water-jets illustrates very well a similar effect of electricity on small drops. A vertical water-jet, 2 feet high, from an opening $\frac{1}{20}$-in. in diameter, scatters into drops and falls as a shower like rain; now a piece of rubbed sealing-wax held about a yard distant from the place where the jet breaks into drops causes the drops at once to cease to scatter—they fall in large drops as in a thunder-shower. The air should be free from electricity beforehand, as the jet is extremely sensitive. A cloud of steam in a bell-jar rapidly turns into Scotch mist and so disappears.

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* Similar results were observed by C. F. Guitard independently in 1850. *Mechanic's Mag.*, Nov. 1850.

Lord Rayleigh has found * that if a jet of water, falling into drops, be subject to moderate electrical influence, a spherule of water which has been separated amalgamates with a larger mass at the first opportunity. Two perfectly equal and equally electrified spheres would repel one another at all distances, but, if there be the slightest difference in size or electrification, the repulsion will be exchanged for attraction before actual contact is attained.† This attraction will be local, and thus the opposed parts of the surfaces may come into contact with considerable violence, even when the relative motion of the centres of the masses is small. It is easily shown experimentally that violence of contact tends to promote coalescence.

Experiment has shown ‡ that when a jet of steam is electrified, the density of the shadow is at once increased, and the shadow of the visible steam assumes an orange-brown hue. The electrification "appears to promote coalescence of the

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* Proc. Roy. Soc., May 1879. † Ibid., June 15, 1882.

‡ Proc. Roy. Met. Soc., May 1891.

minute globules of water contained in the jet, and perhaps to render condensation more rapid."

The recent experiments of Aitken [*] afford a different explanation of such phenomena (see p. 153).

53. DEVELOPMENT OF AERIAL ELECTRICITY AND THUNDERSTORMS.

In the region of calms there is said to be a thunderstorm almost every day, of great violence.[†] In the mountains above Port Royal, Jamaica, thunderstorms occur every day soon after noon during five months of the year, evidently due to the upcast of heated and vaporous air then established. Similar periodic thunderstorms are observed nearly every day for three months along the mountains of Natal, up which a moist warm sea wind blows almost continuously during the hottest season.

The vapour which ascends quietly from large spaces of water, like oceans and seas, is the great source of positive electricity in the air.[‡] But it occasionally happens, from some local cause of reversal of the ordinary state, that negative force is developed in limited spaces of moist ground in such abundance that it quite overcomes the positive charge of the superincumbent air. It is a negative charge which is then carried up with vapour into the clouds. But when this occurs there are usually positively charged clouds floating high in the air, which have received their store from the oceanic evaporation. The lightning then flashes from cloud to cloud . . . When many isolated showers are falling simultaneously at short distances apart, there are numerous tracts of positively and negatively electrified spaces side by side, the air between the negative rain-clouds being positive. During six days spent on the Faulhorn, M. Peltier noticed that when the snow came from white (upper) clouds it was invariably positively electrified, and that when sleet fell from dark clouds it was negatively charged.

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[*] Proc. Roy. Soc., li. 408.

[†] *Science for All.* Article by Dr. R. J. Mann, F.M.S.

[‡] Ibid. Article on 'Lightning,' by Dr. R. J. Mann.

The higher region of the cirrus clouds is charged with the usual positive form of electricity which is the constant and natural production of the vapours that rise from the sea.* But the storm-clouds which are generated in the heated upcast from the land were shown by Peltier to be constantly saturated with negative electricity.

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* *Science for All.* On 'Hail,' by Dr. R. J. Mann.

CHAPTER IV.

THEORIES OF HAIL.

The opinions and theories of many of the most eminent observers and meteorologists will be found in the following pages. Some, such as the ingenious idea of Volta, which was long in the front rank, are omitted as no longer tenable.

Mr. Cleveland Abbe states that "a very complete synopsis of the various theories of the formation of hail is given by Dr. T. H. Bauermeister in successive numbers of Dr. Klein's excellent popular scientific journal *Gaea*."

54. Remarks on the History of the Subject.

Bauermeister reviews the history of the subject from the time of Musschenbroek, and gives especial attention to the views of Volta, Leopold von Buch, Muncke, Mohr, Reye, Lucas, Baumgartner, and Dellmann. He concludes, however, by saying that, previous to any critical discussion of these different theories, it is, above all, necessary that there should be as full as possible a collection and short description of all hailstorms that have been scientifically observed with reference to the form of the clouds, the direction of the wind, the atmospheric electricity, the topographical distribution, as well as a collection of the results of scientific balloon-voyages, and as many as possible observations on high mountains.

"Professor Fritz,* of Zurich, has published a characteristically thorough memoir on the geographical distribution of hail.

"The classification of hailstones according to their external characteristics has been attempted in considerable detail by Prestet.

"The formation of hailstones is considerably elucidated in a short article by Flögel, of Bramstadt, who, in some remarks upon a memoir by Reynolds, explains that the observations made by himself, and in 1791 by Wilke, and in 1844 by Schumacher, all point to the conclusion that a crystal of snow or ice, having once been formed at a considerable altitude, and descending rapidly, grows in size only by additions to its lower side; if, therefore, its original shape allows of it, it will keep the same end always uppermost, and will grow into a conical mass of ice, which will on its exterior be marked by ridges or striæ corresponding to the angles of the original crystal. The question as to whether hailstones are to be considered as built up from the sphere or the cone as nucleus is settled by K. Fritsch, whose great experience enables him to say that both are equally common."

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* Extract from 'Physics of the Globe,' by Cleveland Abbe, Washington, D.C., Nov. 5, 1878, pp. 78–9.

55. EPHEMERIDES OF MANNHEIM.*

"In seventeen of the heaviest hailstorms which occurred in S. Germany, the barometer rose in three cases from the evening before till the time of the storm, but the maximum rise was only 1 mm. In all other cases the barometer fell, the mean fall being 2·5 mm. After the hail, pressure remained stationary in two cases, fell in one case, rose in fourteen cases. It is often observed that after hail the weather remains unsettled for whole weeks; in particular, hail is followed by cold."

"Out of six hailstorms which occurred at Padua during the summer months, the mean temperature at St. Gothard at 2 P.M. was only 3°·5 C., several degrees below the mean of the month. Several times during the afternoons the temperature fell below 0° C., and in the evenings it frequently fell 5° below 0°." This gives a proportionate fall of 1° C. for 114·4 m. ascent instead of for 195 m., the mean. "On the hottest day of hail at Padua the temperature was 29°·4, on St. Gothard 5°·8, which gives a decrease of 1° for 87·8 m." There would prevail, in this proportion, a temperature of – 9° C. at 3900 m.

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* Kämtz's 'Meteorology,' p. 384.

Kämtz thinks an upper layer of cloud is first formed in a hailstorm, and plays the most important part. "If we reflect that cirri float at a height of 6000 m. and more, for I have never seen them below the high summits of the Alps, we can understand that the region in which these flakes are suspended is at a temperature very much below 0°. The heating of the ground being very unequal, the ascending currents have also a force and extent differing very much; hence the horizontal winds in the higher regions."

56. Dr. Reye on Unstable Equilibrium.

Dr. Reye, of Zurich, has calculated* from mathematical considerations of atmospheric equilibrium, that even with a decrease of only 3°·49 (?) for 100 m., an unstable equilibrium is possible, which with the least disturbance, as, for instance, the shadow of a cloud, or the influence of a rapidly ascending local current, may result in a sudden violent downrush of air from the higher regions.

57. Mr. Ley's Account of the Development of a Heavy Shower.

Mr. Ley † gives the following account of the development of a heavy shower or thunderstorm:—

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* See 'Über krystallinischen Hagel im Thrialetischen Gebirge,' Abich.

† See Abercrombie's 'Weather.'

"Under a summer sky a massive cumulus begins to form a few miles distant from the observer. The atmosphere being nearly calm up to the height of nearly 12,000 or 14,000 feet, the cumulus preserves its hemispherical form, and an enormous aggregate of cloud-matter is produced, the contents of which may occupy a space of upwards of 100 cubic miles, while the extreme opacity of the cloud shows that the water-spherules which compose it are somewhat closely packed. No rain falls from such a cloud while it preserves the hard outline of its upper portions and its general hemispherical figure. Suddenly the summit of this cloud becomes soft-looking, and spreads out laterally in cirriform fibres, this change being always simultaneous with the fall of a sheet of rain out of the cloud. The electrical charge, which prevented the collision of the particles composing the cloud while these particles remained spherical, has been suddenly diminished in the upper portions of the cloud as soon as these particles are congealed into ice-needles, from the edges and extremities of which the electricity immediately escapes. The particles, now only moderately electrified, unite, and in their rapid descent absorb the smaller spherules with which they come in contact. The falling rain, and perhaps still more rapidly the disruptive discharges, if such occur, further tend to tap the electricity of the cloud, i. e. to lower the potential of the cloud-mass, and the shower-making process continues till all, or nearly all, of the lower portion of the cloud has disappeared."

Abercrombie says, "The cirrification of rain-cumulus is certainly not necessary to precipitation. . . . Lord Rayleigh has proved experimentally that moderately electrified drops tend to coalesce, strongly electrified drops to repel one another." . . . "The flash, the clap, and the splash of rain or hail, may be supposed really to occur simultaneously."

58. Dove on Hail.

Dove wrote,* in 1857, with regard to hailstorms, "that the kernel of soft hail, which forms in the high atmosphere, is often carried round and round in the inclined whirlwind, and gains a deposit of ice upon itself, until it grows so heavy that it falls. The peculiar noise before a hailstorm is due to the whirling movements of the stones before they fall. Such hailstorms and many thunderstorms have thus the peculiar appearance of long, nearly horizontal, columns of cloud, which, projected on the sky, appear somewhat bent. Since it is in the circumference of the whirl that the hail is longest carried round, and submitted to the greatest changes of temperature, the hail falls most from the borders of the cloud, and hailstorms are often double or parallel, with a space between in which only rain falls. This explains also the narrow area over which hailstorms prevail. The disturbance being merely local the barometer is little affected, for it measures the total pressure of the circulating air."

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* See Abich.

A little snowflake or grain of ice, carried up rapidly in an eddy through air containing thick clouds of particles below 32° F., but unfrozen, will grow into a sphere of ice.* But in falling, water will be deposited and freeze on the lower side, which thus grows larger than the upper side. Müller has observed† that the different forms of snowflakes depend on the absolute and relative degree of saturation and the temperature of the air. Snow crystals or crystals of ammonia vapour have been artificially produced of various forms. Snow crystals with an angle of 120° and 60°, of which Scoresby described 96, C. Martins 20, and of which the varieties amount to some hundreds, may be divided into five principal sorts. 1. Thin laminæ, in very great variety, six-rayed or hexagonal. 2. Flakes with a spherical nucleus, and with rays ramifying in different planes. 3. Fine six-sided needles or prisms. 4. Six-sided pyramids. 5. Six-sided prisms, from which six-sided plates project at one or both ends.

59. DUFOUR'S EXPERIMENTS, ETC.—ABICH.

In order to cool a mass of water below zero, without contact with solid bodies, Dufour‡ uses a dry glass, moistens its sides with oil of almonds; then pours in such a quantity of chloroform as causes the water to be freely suspended in the form of a sphere. If the whole is now cooled down, the water begins to freeze usually about – 10 C.; but small spherical drops sometimes remain fluid at – 18° or – 20°. Touching such a spherule of water with a piece of ice immediately induced solidification, but when the water was touched with glass or wire, it did not always freeze. The electric current from two Bunsen elements did not cause solidification at – 7°; the filling of a Leyden jar through the drop did not always freeze it.

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* See Abich.

† 'Lehrbuch der Kosmischen Physik,' von Dr. Johann Müller.

‡ Archives des Sc. Phys. et Nat., t. x. p. 346, April 1861, quoted by Abich.

In further experiments* Prof. Dufour succeeded in maintaining drops of several other substances, such as sulphur, phosphorus, &c., in the liquid state when many degrees below their point of solidification. Thus drops of melted sulphur 0·5 mm. in diameter, in a bath of chlorate (chlorure) of zinc, remained liquid at 110° below the ordinary temperature of solidification. Prof. Dufour discovered, after putting forward his theory of hail, that M. de la Rive had, in his 'Traité d'Électricité,' suggested the formation of hail by the passage of grains of ice or snow among globules of water below zero, and rejoices in the experimental demonstration he has been able to give of the idea of that eminent man of science.

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* 'Sur la Solidification de quelques corps,' par M. L. Dufour. Extr. des Archives des Sc. Phys. et Nat., Bibl. Univ., mai 1861.

Thomson[*] notes the fact that hail falls on the summit of Mont Blanc. He attributes the formation of hail to the co-existence of sudden and intense cold in a humid atmosphere.

Mohr considers thunderstorms the general form of disturbed condition, of which hailstorms are the most accentuated examples. Abich[†] agrees with Hann and Dove that the descent of cold air from a height in local whirlwinds is the condition which may rationally be assumed as giving occasion for hailstorms.

Prof. Daniel Colladon[‡] asks how it is that certain places, certain valleys, are subject nearly every month to hailstorms; and, if hailstorms are gyratory tornadoes, why are not the whirling movements visible? The parts of cumulus concerned are often distinct from each other, as shown by the lightning flashes between them.

60. THEORIES OF HAIL. SCHWAAB.[§]

Seifferfeld found that a drop of water placed on the conductor of an electric machine at – 13° R. was instantly frozen into milky ice when a spark passed through it, while those through which a spark did not pass remained fluid. But this is rather a proof of agitation, not especially electricity, causing congelation.

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[*] 'Introduction to Meteorology.' See also Abich.

[†] 'Über krystallinischen Hagel im Thrialetischen Gebirge,' Abich.

[‡] 'Contributions à l'Étude de la Grêle,' Prof. Daniel Colladon. See also Becquerel père in 'Comptes Rendus,' vol. lxi. p. 813, and vol. lxii. p. 309. See also Abich.

[§] 'Hageltheorien,' Dr. W. Schwaab, 1878.

With regard to the conditions accompanying hailstorms, Kämtz observes that the proof of a disturbance in the distribution of atmospheric heat is afforded by a great number of facts.* In nearly all hailstorms, the currents of air are violent and the clouds borne in different directions.†

Kämtz's Theory. — Conditions necessary for hail are: Stillness of the air, up to a high altitude; strong heating of the earth by the sun, and abnormal or excessive temperature for the season. The air is then usually near saturation, and is more oppressive than would be indicated by the thermometer. A strong ascensional force is acquired by the lower air, the higher regions of the atmosphere being in comparison much colder than would be the case under the ordinary law of decrease of temperature with height. The ascending vapour therefore enters regions where it is condensed long before the occurrence of condensation through the cold of expansion alone. The cirrus cloud, in which the formation of hail begins, is a snow cloud; its height may be about 18,000 feet, and its temperature – 25° C. The particles of snow or ice falling from this cloud evaporate except when the air is so damp that cumuli are formed. The number and extent of the upward currents increase, equilibrium is upset, cold masses of air sink with great rapidity and bring about further condensation. The downward rush causes an indraught of winds from all sides, and we see the clouds driving rapidly in all directions. When the cold mass of air rushes downwards the hailstones will be carried down through the nimbus, and if the granules are large and at a very low temperature, vapour will be condensed upon their surface at every moment; their volume increases in falling. When the particles of hail or snow first fall they encounter warmed air, and the small deposition of vapour takes the form of snow crystals, but later the air becomes cold partly owing to the falling hail and partly to the sinking mass of cold air, and so the point of saturation is approached; the condensed vapour is deposited in ever-increasing quantity on the surface of the hailstone, and cannot crystallise regularly, but forms a thick transparent husk round the opaque snowy nucleus.

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* 'Lehrbuch,' II. p. 535; and 'Course of Meteorology,' p. 382.

† 'Lehrbuch,' p. 519.

Schwaab.—A very cold stream of air presses into the region of thunderstorms. A mixture of strata of different temperatures ensues. Flakes of snow and soft hail are formed, which are carried about by fresh streams of cold air, and so agglomerate. Water from vapour is condensed upon them and freezes. Hence the loose texture of the inner, and the firm texture of the outer part of hailstones. Graupel in spring becomes hail in summer. But, it is objected, the heat set free by condensation is great. To this Schwaab replies that *radiation* in the higher regions disposes of this heat.

Vogel pointed out that the cloud may be in the form of watery particles and yet far below the freezing point; soft hail falling through this will then have water deposited on it, which will instantly freeze. Similarly Dufour, de la Rive, and Nöllner.

Vettin says rain formed in the lower half of a whirl of air is carried up and freezes; it is carried down again into the lower portion and condenses more rain upon itself; then, driven upwards a second time, congeals; and this continues till the hail is thrown out of the whirl owing to its weight. The concentric layers correspond to the number of times the hailstone was carried into the upper region, where the temperature was below 0°.

Mohr considers that hail is owing to a great rarefaction of the air, which, by its rapid increase, draws in the air lying above rather than that lying around. A funnel-shaped eddy of ice-cold air is formed thus, with condensed vapour and frozen rain brought to earth by a movement resembling that of a screw.

In *Faye's* view, a thunderstorm is the lower end of a powerful funnel-shaped whirl, which has formed in the upper strata of the atmosphere, and breaks into the region of nimbus from out of the region of cirrus. A hailstorm he considers to be equally explained by this supposition.

61. LÖSCHE'S VIEWS.

Prof. Lösche* states that the following are the conditions which produce a hailstorm:—1. A strong undisturbed upward current of vaporous air. 2. An invasion of cold higher strata. 3. Cold nuclei formed at greater heights. Stillness precedes, wind accompanies, cold follows. The short duration of a hailfall is explained by its being a phenomenon due to ascent of heated vapour, and a rush of cold air upon it. Hail falls with the point of the pyramid grains upwards. Often it is round. When stones are found on the ground larger than half a pound they are usually agglomerations of several, frozen together.

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* 'Über Atmosphärische Niederschlage.'

62. Ideler and others on Hail.*

According to Erman, when a body, such as water, is disengaged in the vaporous state from a surface electrically neutral, and rises to a height, it becomes electrified *oppositely* to the sign of the surrounding medium. Therefore the vapour rising from a water surface has minus electricity, the atmosphere usually being positive; and for the same reason the rising air column, which is very strong over dry ground where there is little vegetation, and its vapour, has a minus or negative sign. Gay-Lussac and Biot found, in their balloon voyages, that the higher they rose the stronger was the minus charge of the air (Gilbert); Hohenwart found the same in his ascent of the Glockner. After the great outbreak of Vesuvius in 1794, the air was minus to a degree never before observed. Thus the precipitated rain, &c., is minus, and isolated objects exposed to the rain give minus in a shower. With snow this is more distinctly the case.

Schübler says,† "the electricity of rain, not only in thunderstorms but in ordinary rain, is, as a rule, stronger according to the quantity of water which falls in a certain time: in a clear sky the electricity becomes stronger the moment a cloud or fog is formed. The longer the distance (height) through which the rain has fallen, the stronger would be the charge.

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* See 'Untersuchungen über den Hagel,' Dr. J. L. Ideler.

† Schweigger's 'Journal,' xliv. p. 232.

The reason why thunderstorms are rare in the tropics is, that when a rainfall takes place it is common to the whole height of the atmospheric column. The same is the case in Polar regions. Thus, in India, with the S.W. Monsoon, storms are rare, but in the other half of the year very common.

Olmsted * explained the formation of hail by the "congelation of the watery vapour of a body of warm and humid air by its suddenly mixing with an exceedingly cold wind in the higher regions of the atmosphere."

M. Faye says † that in the ordinary state of the atmosphere, a column of air which descends is raised in temperature at a greater rate than the normal rate of increase of temperature with lower altitude.

M. Colladon concluded, from observations on the Pissevache waterfall, that an aspiration, or rapid ascent of air, is caused by a falling body of water, and similarly by a falling mass of air.

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* Thomson's 'Introduction to Meteorology.'

† 'Comptes Rendus,' 1875, vol. lxxxi. p. 111.

Electric phenomena of the air depend on the fact that dry air is a non-conductor for negative electricity. Rain occurs when two saturated strata of air of different temperature mix; lightning does not occur when the air is moist enough to conduct the electricity without disruptive discharge. Delcros found hail to consist of spherical pyramids, the conical end of which was often pointed. According to Humboldt, daily thunderstorms occur in many parts of the tropics, but hail is rare.

In Würtemberg the forests are generally free from hailstorms when the cultivated land suffers.*

Hail is a common accompaniment of waterspouts. Cook, in his second voyage, noticed the little puffs of wind surrounding waterspouts and the occasional fall of hail in their proximity. Michaud also observed hail in a waterspout at Nice. This hail was soft and of large size. Favourable conditions for the production of hail are said by Gay-Lussac to be great dryness in the lower strata, and cold currents breaking into warm columns of ascending air.

63. The Formation of Rain.†

Baxendell mentions that the drops of water which drip from the upper part of a shaft increase to an extraordinary size in the descent to the bottom. The temperature of the mine would doubtless be an important factor in this result. Nichol has given the following as the causes of condensation resulting in rain. 1. The cooling of clouds by radiation from them. 2. The mingling of vapours at different temperatures chiefly by the agency of the winds. 3. The rising of vapours towards the colder strata of the atmosphere. 4. The increase of atmospheric pressure. 5. The accumulating and impinging of masses of vapour against some obstacle. No. 4 may well be omitted as there is no reason for admitting its validity, and, on the other hand, rarefaction is probably a cause of rain, as may be exemplified in the laboratory. Another cause of rain is the transference of warm moist air from the tropics to higher latitudes.

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* On this point more recent investigation should be consulted.

† 'Intellectual Observer,' Dec. 1867. Richard Proctor, F.R.A.S.

A quantity of water sufficient to cover an area of 100 square miles to a depth of one inch, would require, to evaporate it, as much heat as is produced by the combustion of half a million tons of coal, and the amount of force of which such a consumption of heat is the equivalent, corresponds to that required to raise one thousand millions of tons to the height of one mile. Since rain often falls in this quantity, that is, one inch in twenty-four hours, the amount of energy set free in the space affected must amount to this enormous sum.

The power which small particles of water, such as those seen in clouds and fogs, possess of building themselves up into crystalline forms, seems to show a possibility of molecular forces overcoming the previous globular arrangement of the water particles.

64. Note on Waterspouts and Whirlwinds.

Waterspouts are considered [*] to be due to rapid eddies of air with *rarefaction*, causing visible vapour condensation in the cold rarified space, which thus becomes apparently *solid* with dense cloud, produced as in the vacuum of an air-pump. The sudden cold produces a very heavy downpour of water from the cloud into which the refrigerated air is carried. The air from the space surrounding the waterspout or whirlwind cannot, owing to rapid rotation, fill the interior space as fast as the air within it is drawn upwards.

According to Ferrel,[†] all hail is probably connected with whirlwinds more or less developed. Rain drops formed below are carried up into the snow region by powerful ascending currents, suspended a little while, and frozen into hail. If now these be thrown quite outside the limits of the tornado, they fall as clear ice. If, however, they are carried in towards the vortex they are again carried up to the freezing region. A number of such revolutions may be made. While up in the snow region, they receive a coating of snow, but lower down, where rain is being carried up, they are coated with clear ice. When the nucleus is composed of snow, as it generally is, the hailstone had its origin high up in the snow region. Ferrel's theory is developed in his book on "Winds."

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[*] See 'Encyclopædia Britannica'; and *Nature*, April 7, 1887.

[†] See 'Meteorological Researches for the use of the Coast Pilot.'

65. OVERCOOLING.

Prof. von Bezold* considers supersaturation and "overcooling" to be possible conditions in the atmosphere. As regards "overcooling," clouds and fogs have been observed consisting of water, not ice, particles, below the freezing-point. A sudden cessation of these states must result in a rapid rise of air-pressure. "Much thunderstorm rain has, high up, the form of hail or sleet, and the large drops are simply melted hail or sleet particles,"

66. FORMATION AND SHAPES OF HAILSTONES: VARIOUS VIEWS.

Prof. Perevoschtchikoff† thinks that the nuclei of hail are congealed drops, and that they acquire in their passage downwards new coatings of moisture on the surface.

Prof. Matteucci‡ conceives hail to be instantly formed in the atmosphere. Vapour is condensed instantaneously into snowy particles, and an icy crust formed, with the aid of electricity. Prof. Stevelly agreed in this view.

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* 'Thermodynamics of the Atmosphere,' Berlin Academy, 1892.

† See Kämtz's 'Meteorology.'

‡ Ibid.

Kämtz considered the pyramidal to be the primitive form, while Descartes, Airy, Elie de Beaumont, Delcros, and Nöggerath believed the primitive form to be a sphere which broke up in the fall.

The following forms have been observed: pyramidal, octahedral, stellated, angular, tabular, conical with a serrated base, spherical, elliptical, irregularly polyhedral, and amorphous. The usual size is from $\frac{1}{10}$ to $\frac{1}{4}$ in.

67. M. DUFOUR'S EXPERIMENTS AND THEORY.*

A mixture was made of oil of almonds and of petroleum in equal quantities, and a small quantity of chloroform, so that the fluid was of the same density as water. The point of equal density is ascertained by letting a drop of water fall and making the mixture such that it will hold the drop in suspension. M. Dufour found that drops of water thus surrounded by a tranquil medium could be lowered to – 4°, – 8°, and even – 12° without solidifying. From – 8° to – 10° the globules usually froze rapidly throughout, but the smallest drops often lasted longer in the liquid state, sometimes down to − 18° and − 20°. Upon freezing, the drops of course expanded, and owing to their less specific gravity, at once rose to the surface of the medium. The drops could usually be touched and distorted with a stick of glass without immediately freezing. Various crystals did not seem to congeal the drops on contact, but a crystal of ice produced immediate congelation.

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* 'Sur la Congélation de l'Eau et sur la Formation de la Grêle,' par M. L. Dufour, Lausanne. 'Archives des Sciences de la Bibliothèque Universelle,' April 1861.

Frozen globules at − 6° or 7°, and 3 to 5 mm. in diameter, when brought into contact with globules still liquid cause instant congelation of these, which are isolated from the first or lightly in contact with them. The drops then look whitish, like soft hail. If the temperature of the frozen particles is somewhat higher, − 3° to − 4°, the liquid drops spread out upon them in the act of freezing and form prominences upon them. At a still higher temperature, − 2° to − 1°, the liquid drop brought into contact with the solid does not instantly freeze but forms a liquid envelope round it, which soon freezes, and the same thing happens with other drops brought to it in succession. Small drops brought into contact with a frozen globule at − 6°, and then quickly withdrawn, produced spheres equal to 4 centimetres cube, and more. A variety of results occur according to temperature, the size of the drops, &c.

"It is not uncommon to see in a very humid fog, objects in the free air streaming with moisture, while the thermometer is below 0°."

When a snow or ice particle is formed *much* below the freezing-point, and then falls through dense cloud below the freezing-point, the agglomeration and solidification occur upon it rapidly during its passage through the cloud.

Dufour considers that a solid globule coming in contact with others still liquid, will be enveloped by them, before they freeze; smaller globules will partially spread out on the nucleus before freezing, forming a boss or projection. Some stones will be formed by the agglomeration of small granules.

Leopold de Buch considered the layers or strata in hailstones very common, with an opaline nucleus. Kämtz saw hailstones with a snowy nucleus surrounded with perfectly transparent ice. The lenticular form has been observed by him and by Adanson.

Peron has seen long hailstones like irregular prisms. Arago has seen hailstones with clear nuclei. Volney saw, in the storm of July 13, 1788, irregular hailstones with long projections. In the storm of August 23, 1850, in the Canton of Vaud, hailstones were observed of a round, oblong, and flat shape.

Deluc considers the snowy kernel to be general, and Denison Olmsted speaks of it as frequent.

Arago speaks of large hailstones sometimes having a snowy nucleus, surrounded by concentric layers of ice alternately clear and opaque.

Kämtz saw, in the storm of June 11, 1827, many hailstones having a round opaque nucleus of a line in diameter, the total diameter of the stones being from 2 to 4 lines.

Particles of hay have been observed in hailstones by Citano, Scheuchzer, and Fromondus. In 1755, in Iceland, each hailstone inclosed a little sand or volcanic ash. In 1821, Pictet recognised sulphate of iron particles in the centre of hailstones which fell in Iceland.

Dr. Waller, in his microscopic examinations of hailstones, found that there was always much air contained in them, sometimes more than ice. He states the temperature of hailstones to be – 3° to – 4° C.*

Muncke mentions a fall of hail at Hanover, when the temperature fell to 5°, having been 31° before the fall.

Dufour concludes that condensation of vapour, and precipitation of water-globules below 0° C. are the two principal causes of hail.

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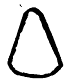
* 'Archives,' 1846, vol. iii. p. 30.

68. Prof. Osborne Reynolds' Experiments and Theory.[*]

Hailstones observed by Prof. Reynolds have always been conical or pyramidal in shape 

Manner of formation suggested:—A particle of ice starts to descend from some point within or at the top of a cloud, which cloud consists of small particles of ice; the particle in its descent sweeps up the particles of ice in front of it, which, sticking to its lower face, add to its size, and give it the conical form, some of the particles striking the falling mass so near to its edge as to overhang, so that the breadth of its face is continually increased.

The weight of small particles of water is proportional to the cube of their diameters; the surface exposed to the resistance of the air is proportional to the square of the diameter; so that the resistance of a particle of half the diameter of another would be one-quarter as great, but the weight only one-eighth, so that the velocity of the smaller drop would be only half that of the drop of double its diameter. At very small velocities, Prof. Stokes has shown that the resistance is proportional to the velocities. Thus small drops of rain, or particles of a cloud, descend with a velocity proportional to their size.

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[*] 'The Formation of Raindrops, Hailstones, and Snowflakes,' Osborne Reynolds, 1878.

Clouds consist of particles of different sizes. In order that the particles may aggregate, it is essential that they should combine when they encounter. Clouds often—commonly, in fact—exist without rain. Some fogs deposit moisture on all exposed objects, others do not.

When the cloud-particles come together and combine, rain is formed; when they do not combine, rain is not formed.

Sometimes the rain from a cloud evaporates before reaching the earth.

About the densest cloud we can conceive of is one which would result from the cooling of air from 65° to 32°; such densities may be attained in summer. Clouds are often several miles in thickness, particularly the heavy summer clouds which give rise to the larger drops.

Mr. Baxendell first pointed out that the amount of latent heat resulting from condensation is so considerable, that a cold drop could only receive a very small addition to its bulk before its temperature would be raised to any temperature the air might have. A condensation of a tenth of its own weight would raise its temperature 100° F. It may be that air is sometimes cooled far below its dew-point without a cloud being formed, and in such a case the drop might grow to a considerable extent by condensation. Such a condition of air, however, has never been observed.

The granulated texture, conical shape, and striated surface of hailstones, all bear testimony to their being the result of a particle having started to move in one direction in a cloud of ice-particles, and sweeping the ice-particles as it advances, and this testimony is greatly strengthened when we come to examine the stones more closely.

The base of a hailstone is much firmer in texture than the vertex. This increase in firmness is what must result from the increase of velocity as the stone acquires a larger size, for, as its speed increases, the force of the collisions, as it overtakes the frozen cloud-particles, must increase, and hence that portion of the stone which is formed last will be the firmest.

When a cloud of water particles is cooled by elevation and expansion, or by radiation, down to a temperature below 32° F., the fog becomes frozen, but the particles retain their spherical shape practically unaltered, and the result of such a cloud is hail; but when air at a temperature below 32° is further cooled, the vapour condenses into a solid state—is, in fact, deposited as ice upon ice, and hence we have the crystal. Snow occurs often when air and clouds are below 32°, but it is the dense cloud of the higher temperatures which gives rise to hail. When a body of heavily saturated air, at a temperature of 60° or 70°, suddenly ascends, as it rises it forms into a cloud, three-fourths of its vapour will be condensed before its temperature falls to 32°, and when this is reached the water particles are frozen into ice particles of the same shape, and it is these frozen spheres which form the hail. The time occupied in falling through a cloud would, in all probability, be very considerable —from five to ten minutes at least after the stone had acquired a considerable size.

Prof. Osborne Reynolds has formed artificial hailstones or icestones by using a jet of ether and water in the form of spray, directed against a splinter of wood. The speed of the blast is from one and a half to two miles a minute, and the larger stones, about half an inch in diameter, traverse one to four miles of spray during their formation.

69. PLUMANDON'S VIEWS AND OBSERVATIONS.*

When the sky is clear and the air damp, the air heated by the sun near the ground rises and reaches a level where the air is comparatively cold. There the warmer and damper air has its vapour condensed upon the minute dust which the air always contains, and light clouds are formed above the moistest and hottest places. On the sides of the Puy de Dôme, ascending currents of this kind are often experienced, succeeding each other intermittently, in a calm air, after rain. They rise at a rate of 4 or 5 metres at least per second. These cloudlets station themselves or oscillate in a stratum of equal density to their own. There they accumulate to form a cloud or group of clouds increasing in size.

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* 'Formation des Principaux Hydrométéores,' J. N. Plumandon, Météorologiste adjoint à l'Observatoire du Puy-de-Dôme, 1885.

Such a cloud-mass becomes heated by the sun in the interior, and protuberances develop on its summit with great rapidity; meanwhile the edges at the circumference rapidly cool by radiation or evaporation, and quickly descend.

The upward movement of air (produced by mountains or other obstacles) causes its refrigeration, both by expansion and by mixture with colder air. But this does not explain all rain. For how does it rain on the ocean, where no obstacle forces up the air?

There are five different kinds of cloud and rain states:

1. Fog; air near saturation, but no rain or moisture falls. Objects are not wetted.
2. No fall of visible particles of water in the cloud, but all objects are rapidly wetted. In this region the rain begins to form.
3. Very fine drops of rain in the midst of the cloud,—it drizzles.
4. Rain; fog or cloud remains.
5. Rain, but no fog or cloud, one is below it.

These five cases may be met with in the same cloud.

At the altitude of the Puy de Dôme, rime is formed with all the wetting fogs or clouds when the temperature is the least below 0° C. It forms when one could not have supposed there was the least liquid condensation. It is very frequent and attaches itself to all exposed objects. Sometimes the layer of rime deposited is enormous: 0·1 metre on the ground, 0·3 m. on the telegraph wires, 0·5 m. or 0·6 m. on the lightning conductor, 0·8 and even 1 metre on the mast and ladder of the observatory on the tower. The rime is formed with all winds, even the most violent. It is often much more dense than that which forms in the lowlands, and is like opaque ice of a granular texture. The particles agglomerate under the considerable pressure exercised by the wind, which hardens the whole mass. The wind blows often at 30 to 40 metres per second. It is possible that the particles are in a very delicate state of surfusion when the temperature is below 0°, and that they solidify the moment they come in contact with obstacles, especially with rime already formed.

M. G. Tissandier, in a balloon, at 1200 metres, with a temperature of — 2, saw his instruments quickly covered with rime, consisting of little plates of hard ice.

Snow crystals are formed at a temperature below 0°, in conditions similar to those which produce drizzling rain. Snow crystals have been artificially produced by projecting into a very cold space finely divided jets of water.

In Laponia, Bravais and other physicists have observed that when the door of a house is opened the vaporous air of the warm room is sprinkled with small crystals, which float in the air.

The brothers Tissandier observed, in a balloon ascent, that the size of the snow flakes diminished as they rose, till at 2100 metres the air was translucent, and little needles of ice were seen to fall and to agglomerate in falling. The temperature was – 7° C.

When it rains at Clermont, snow is often observed on the neighbouring hills, less than 1 kilometre distant, and 600 feet higher.

The remarkable showers of large drops with a clear sky may be explained by the descent of crystals of ice, increasing in size as they fall and then melting in the lower air. Clouds composed of ice-crystals are often invisible, when not thick.

A considerable amount of cold is produced by rapid evaporation. Glaisher saw his wet bulb thermometer descend to – 3°·3, while the dry bulb thermometer was at 2°·9.

M. Fautrat, inspector of forests, has found that the quantity of vapour in the air over forests is much greater than in the air over the open country.

M. Dehérain has stated that a young blade of corn (wheat) evaporates in one hour a weight of water equal to its own.

M. Boussingault has calculated that a field of cauliflower of one hectare, where the plants are 0·5 metre apart, can emit in 12 hours 20,000 kilogrammes of water.

M. Peltier has shown by experiments with kites and electrometers, that the transparent vapour masses of the air are grouped like visible clouds, but are more continous.

The astronomer, Tempel, thought that his observations showed the atmosphere to be divided, not only into horizontal strata, but into vertical compartments differing greatly from each other.

If a small spicule of snowy ice passes through regions where vapour has been already transformed to water, its volume increases rapidly where the cloud only moistens, rapidly where it drizzles, more rapidly still where it rains. If the snowflake or spicule was liquefied completely, the resulting water forms a drop of rain, and the hailstone formed from it will be spheroidal. If the granules undergo partial meltings followed by re-congelation, their forms will be various, and will resemble those of an ellipsoid, an egg, a pear, a walnut, or lenticular plate. If the snowflake was not completely liquefied, and the water of fusion cannot quite envelop the snowy part which remains, the hailstone will have a more or less irregular shape, reproducing roughly the angles of the snowflake outside the drop of water. If the shape be irregular in the early part of its course, the hailstone will maintain the same position in falling, and as it traverses clouds of various density and temperature will be still more irregularly increased or diminished.

M. Cailletet has collected hailstones of a temperature of −9° C., and M. Boussingault of −13° C.

Rate at which hail can fall.

Diameter.	Rate beyond which Hail cannot fall per second.
mm.	m.
1	2·21
2	3·13
3	3·83
4	4·42
5	4·95
6	5·42
7	5·86
8	6·26
9	6·64
10	7
20	9·90
30	12·12
40	14

Many persons think the clouds which form hail are very low. M. Plumandon, with Herr Hann, of Vienna, does not share this view, but believes the fall of hail from low clouds to occur very rarely. Nearly every time when he has been able to observe the cloud-masses when a storm was going on at a certain distance, he saw the upper part of the cumulus transform itself into cirrus. Sometimes clouds of a cirriform appearance were developed on the flanks of the cloud-masses, and sometimes crowned them like a gigantic mushroom. The summit of the cumulus must therefore have been at least 12,500 feet high. The storm did not seem to break until this curious formation of cirrus or pallio-cirrus took place. The great height of hail-clouds is proved also by the frequent occurrence of hail in the Alps, the Pyrenees, and on the summit of the Puy de Dôme. Balmat and Paccard observed hail on the top of Mont Blanc at an altitude of 15,700 feet, and M. Boussingault on the Andes at about 19,000 feet.

Taking an altitude of origin of a hailstone of only 12,500 feet, and supposing it to have its *final* mass during the whole of its fall, the duration of its fall will be represented in the following table:

Diameter of hailstone. mm.	Maximum duration of fall.
1	30′·0″
2	21′·18″
3	17′·24″
4	15′·50″
5	13′·28″
6	12′·18″
7	11′·23″
8	10′·39″
9	10′·02″
10	9′·31″
20	6′·44″
30	5′·30″
40	4′·46″

But since the hailstone grows during its fall from a very small original size, and the resistance of the air varies inversely as the square of the diameter, the actual times must be longer than those shown above. An ordinary hailstone of about 0·01 metre in diameter would take at least 15 minutes.

The strong wind which so often accompanies hailstorms, would cause the hailstones to occupy a much longer time in their fall through the air, owing to the much greater length of their trajectory. It is plain that the times occupied are sufficient to allow of the freezing of raindrops or the melting of large snowflakes or hailstones.

It has been shown that hailstones become larger during their descent, and are small at high altitudes. In the tropics, hail, which is not very rare in the mountains, is converted into large drops of rain before reaching the plains. In the arctic regions, hail is small and soft, being formed at low elevations.

Hail is most common at the beginning of storms because there is then the most sudden mixture of greatly differing masses of air.

Boussingault observed, in a descent from a height of 19,500 feet in the Andes, a gradual increase in the size of the hail, from very small grains up to the dimensions of a bullet. These did not, however, fall with sufficient force to cause inconvenience. At a height of about 14,000 feet the mass of cloud or fog was so dense that it was with difficulty he could read the scale of the barometer. Below this region the hail redoubled and fell with great and painful force. The thickness of the cloud, from which they emerged at about 12,700 feet, was about 6900 feet.

70. TORNADOES AND HAIL.*

"Cyclones of a smaller diameter, known as 'Trombs,' at times do great damage in our forests. Their lateral extent is comparatively small; however, in the neighbourhood of the path of their centre they are capable of blowing down trees, unroofing houses, and lifting heavy articles from the ground. In the progress of such a whirlwind its axis frequently receives a considerable inclination in the way it is moving, in consequence of the resistance presented to the motion of the air by its friction with the ground. It is probable that many of our thunder and hailstorms are to be attributed to this circumstance. The grain of sleet, first formed at a great height in the air, makes several revolutions in the inclined whirlwind, and in its passage through the cold and hot strata alternately it obtains the shell of ice, which covers the grain of sleet, like a grain of snow, in the centre, and at last becomes so heavy that it falls to the earth. The characteristic noise which precedes a hailstorm is owing to the rotatory motion of the hailstones before they fall. Such hailstorms, and many severe thunderstorms, present the striking appearance of a long, almost horizontal, column of clouds which rolls along, and when projected on the sky appears more or less bent. At times the dark bank of clouds covers itself with a number of brighter stripes of grayish clouds, which envelope it, as a waterfall does a cliff over which it falls. The edges of the whirlwind seem to favour the formation of hail, in consequence of the fact that there the circles described by the hailstones are largest, and consequently the difference of temperatures which they have to pass through is greatest. It has been very often observed that the district where hail fell, never of great breadth, has been double, with a district in the middle where it has only rained. The reference of the formation of hail to the whirlwind explains the fact that the boundaries of the hail district are often very clearly marked. The barometer is not much affected by hailstorms: they are local phenomena which it cannot indicate, as it measures the total pressure of the atmosphere, and therefore only gives notice of phenomena which are on a great scale."

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* Dove's 'Law of Storms.'

71. FERREL'S THEORY OF HAIL.*

"A hailstorm," in Prof. Ferrel's view, "is simply a tornado in which the ascending currents are so strong, and reach so high up in the atmosphere, that the rain-drops are carried up into the cold regions above, and into the central part within the isobaric and isothermic surface of the freezing-point, where they are frozen into hail. In fact, hail, as well as rain, is almost a universal accompaniment of a tornado, and so, as the latter, it is usually found in the south-east quadrant of a cyclone, and at a considerable distance from the centre, as has been shown to be the case in Russia, by Klosovsky, from observation. Finlay says in his account of the tornadoes of May 29 and 30, 1879, that "rain and hail invariably preceded the tornado cloud from ten to thirty minutes, nearly always attended by a southerly wind." But this applies mostly to the more violent tornadoes, such as were investigated by him, and not to every class of atmospheric phenomena which we have included under the generic name tornado. It has been shown that every isobaric and isothermic surface, however high above the earth's surface, would, in a perfectly regular tornado, and in the case of no friction, be brought down by the centrifugal force of the gyratory motion to the earth's surface near the centre of the tornado, as represented in Fig. 1. The horizontal and isothermic surface, therefore, high up in the air, which separates the strata of freezing temperature above from those of a non-freezing temperature below, would, in case of no friction, be brought down by tornadic action to the earth's surface at C. The effect of friction, however, prevents it bringing the freezing atmosphere entirely down, or, rather, its so expanding and rarefying the air in the central part that the air in consequence is reduced to the freezing temperature down to the earth's surface. But still the air of freezing temperature is brought down in the central part in the form of a funnel considerably below the general level of its base when undisturbed, just as it has been shown the cloud region is. . . . In the ascending current of a tornado, as in that of the equatorial calm-belt or of a cyclone, the rain-drops are formed down in the cloud region and carried upward until they become too large to be supported by the current, and so fall to the earth. In a tornado, however, the ascending current is often so strong that the rain is supported until by the blending of the small drops by coming in contact, very large drops are formed, and the strong ascending currents often extend so high that these large drops are carried away up into the region of freezing temperature. They are there frozen, and after having been carried up and outward to a distance from the centre where the ascending current is not strong enough, by the formula of paragraph 247, to keep them up, they slowly descend, and receiving additions of ice as they fall, as long as their temperature remains below zero, from the rain below, which is being either kept suspended in the air or being carried farther up, they finally fall to the earth as solid hailstones. But the origin of the hailstone is often not a raindrop, but a bunch of snow formed in the snow region, and moistened by the rain carried up into the region before it has had time to become frozen into hail. This moist snow is kept up there until it freezes, and after that, while being kept up there, and after it commences to fall, as long as its temperature remains below zero it continues to receive a coating of ice from the rain which is carried up past it, and that through which it falls. As it grows and is carried outward above, where the ascending current is weaker, it finally becomes too heavy to be kept suspended in the air, and it falls to the earth a hailstone, with *a kernel of frozen snow in the centre.*" Again, it may happen that "in falling, even through the lower part of the snow region where there is little snow, but mostly rain-drops not yet frozen, it receives another coating of solid ice; for its temperature having been reduced considerably below zero, it continues to freeze the rain coming in contact with it for a long distance after having passed down into the cloud region. But in gently falling down it may be drawn in a second time toward the centre and be carried up by the ascending current into the snow region and receive another coating of wet snow over the last one of solid ice, and in falling receive another coating of solid ice in the same manner as before. This process may be repeated a number of times, in each of which the hailstone, disregarding its gyratory motion all the while, describes a kind of orbit, not returning into itself, until finally it is carried so far from the centre, or the strength of the tornado becomes so much weakened, that it is no longer carried in toward, and up in, the central part, but falls to the earth *a hailstone with a snow-kernel and a number of alternating concentric coatings of solid ice and frozen wet snow.*"

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* 'A Popular Treatise on the Winds,' W. Ferrel.

72. Oltramare's Theory of Hail.*

The experiments and observations of Dufour, Fournet, Jamin, and others, have proved that small particles of water such as compose fogs and mists, may be reduced in temperature to −14° C., or even to −20° C., without being congealed, provided they be not agitated in the least. The slightest shock or concussion causes solidification.

Lord Rayleigh has shown that a weak charge of electricity makes small drops coalesce. When a cloud is highly charged, the particles are kept apart by repulsion; if a discharge takes place, the repelling force is gone and the particles coalesce. M. Oltramare's theory may be enunciated thus:—Let a cloud be (1) electrified and (2) cooled below the freezing-point; the discharge of electricity allows the constituent particles to unite, and the resulting commotion causes instantaneous congelation.

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* M. Oltramare's 'Theory of Hail,' Academy of Sciences, April 1879; 'Lord Rayleigh's Observations on the Behaviour of Electrified Drops,' by J. A. Westwood Oliver, Proc. Met. Soc., June 1881.

73. "METEOROLOGICAL DATA."[*]

The quantity of water actually contained in a cubic foot of air, saturated with moisture, appears to be about 2 grains at the freezing point, 4 grains at 48°, six grains at 60°, and 8 grains at 68°, and the density of the vapour thus mixed with air is, according to the experiments of Saussure, about three-fourths of that of the air itself; so that moist air is always a little lighter than dry, and the more so, as the air is warmer, provided it be saturated by means of the presence of water. (Young.)

The weight of water sustainable in the air as vapour is very greatly increased with increase of temperature, and equal increases of temperature are much more effective in increasing the amount of vapour in hot than in cold weather. The vapour sustainable at 80° is 1·001 inch, at 70° it is 0·727 inch, at 60° it is 0·52 inch, at 40° 0·264 inch, and at 30° 0·186 inch. Thus a mass of saturated air at 80° would, on being cooled to 30°, lose more than four-fifths of its total contained vapour.

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[*] The following notes are extracted from Howard's 'Climate of London.'

The larger drops of *rain*, which are about one-fifth of an inch in diameter, will fall 2040 feet in a minute; but the ordinary drops in this climate will seldom fall half as fast. Hailstones in the south of Europe, having the enormous diameter of 2 inches, will fall with a velocity of 113½ feet in a second, or more than a mile and a quarter in a minute—a rapidity of stroke which destroys corn-fields, and ravages vineyards.*

Prof. Leslie has computed † that hailstones sometimes fall at the rate of 70 feet a second, equal to 50 miles an hour, or 4 miles in five minutes.

Cold rain in large drops is the most intensely electrified of any. Howard says that the positive common to fair weather yields to negative before rain. Above 40 cases in 100 give negative in rain, although the atmosphere shows positive before and after rain. Snow and hail unmixed with rain are positive almost without exception.

Nearly 40 per cent. of cases of rain showed both kinds of electricity, and sometimes one shower following another was differently electrified.

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* Leslie's 'Elements.'

† See Daniell's 'Meteorology.'

Schübler found that during storms, or when it rains or snows, electricity is sometimes positive, sometimes negative, and much stronger than in fine weather. The number of days of positive precipitation was 71, and of negative 69. Storms never take place unless more than one stratum of cloud is present.

"Each of the first minute globules which are precipitated from the vapour will possess its own small share of electricity upon its surface, and as long as the globules remain isolated and thinly scattered there it will remain. When the globules begin to coalesce the electricity will still seek the surface of each increasing drop, and will increase in intensity. When condensation takes place more rapidly the whole body of the cloud may be looked upon as a good conductor, and the electricity, as it is set free in the interior, will at once fly to the general surface, and by this process of concentration the force (which was at first, when diffused over a wide space, of low intensity) acquires an enormous tension." *

74. METEOROLOGY OF BEN NEVIS.†

"The formation of snow crystals on objects when temperature is low proceeds often at an

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* Daniell's Meterology.

† Buchan.

astonishingly rapid rate. All belong to the feathery or fir-cone type. The rate of growth varies with the density of the fog and the speed of the wind. The average rate of growth is about half an inch per hour. A rate of 2 inches has been reached. With a damp feeling in the air the crystals are icy and hard, but with a temperature considerably under 32° the crystals are looser in texture.

"About the time when St. Elmo's fire is seen, heavy showers of snow and snow-hail occur. The snow-hail is in the form of small cones with spherical bases, and is hard and dry but not icy."

CHAPTER V.

CERTAIN PROPERTIES OF VAPOUR, WATER, AND ICE, AND CONDITIONS OF THE AIR WHICH MAY BE CONNECTED WITH THE FORMATION OF HAIL.

The following observations are of value in considering the particular states of air, vapour, and water, which are likely to favour agglomeration in the solid form, especially in the upper regions of the atmosphere.

75. Some Properties of Water: Regelation.*

Tyndall observes that if you enter one of the dripping ice-caves of Switzerland you have only to press for a moment a slab of ice against the roof of the cave to cause it to freeze there and stick to the roof. Moreover, that a number of fragments of ice in a basin of water, even if it be warm, can easily be made to freeze together where they touch by a little pressure. It thus appears that particles of ice driven forcibly against each other when their surfaces are near the melting-point, or, though several degrees below it, still in a liquid state, must adhere together when the surrounding air is below the freezing temperature.

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* See 'Forms of Water,' by Professor Tyndall.

76. Lowering of the Point of Congelation.

M. Boussingault filled a hollow steel cylinder with water and chilled it. The steel resisted the expansion of the water, which consequently remained liquid at 30° F. below the ordinary freezing-point. On opening the tap, the liquid, relieved of the pressure, was instantly converted into ice. Water, even in open vessels, may be lowered many degrees below its freezing temperature and still remain liquid. But if into this water a particle of ice is thrown, solidification at once sets in. If a small particle of ice be let fall upon the over-cooled water ice at once grows from that particle, but not upon the sides of the vessel.*

Very frequently, water in a glass vessel may be found over-cooled on a frosty morning, when the addition of a bit of ice in a very few seconds entirely changes the appearance of the liquid.†

The latent heat set free on congelation does not prevent the process from being a rapid one. In the case of a minute particle of water in air, brought into contact with a small crystal of snow or ice, a certain rise of temperature would no doubt momentarily occur in the still unfrozen portion, but the surrounding cold air and its own rapid radiation would instantaneously bring this portion also low enough in temperature to freeze. Much heat is set free, theoretically sufficient to raise seventy-nine times the weight by 1° C., but the smaller the isolated volume of water which freezes in a cold medium, the less would this liberated heat delay the freezing process. This fact is generally neglected.

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* See 'Forms of Water,' by Prof. Tyndall.

† 'An Elementary Treatise on Heat,' Balfour Stewart.

In capillary tubes, water may fall to – 20° C. without freezing, according to M. Despretz.

77. Soft Ice. Gradual Liquefaction.

Balfour Stewart observes that "Person's deductions from Regnault's experiments are in favour of the view that soft ice possesses more latent heat than hard ice. On the whole, we think the gradual liquefaction of ice is a view which appears not only to be supported by analogy, but to be the best explanation of observed facts." Gradual solidification may be equally possible with gradual liquefaction, and the soft ice of graupel may, while forming, lose latent heat gradually. The water-particles from which it was formed would have less latent heat than water at 0° C., being usually several degrees below that temperature, and perhaps more than proportionally deprived of their original latent heat.

78. LIGHTNESS OF AQUEOUS VAPOUR AND OF CLOUD-PARTICLES.*

"There are various liquids whose weight is not greater than that of water, while the weight of their vapour, bulk for bulk, is five or six times that of aqueous vapour. When those heavy vapours are precipitated as clouds, which is easily done artificially, their particles are found to be far coarser than those of an aqueous cloud. Indeed, water is without a parallel in this particular."

79. RATE OF FALL OF SMALL DROPS.

Stokes calculates that a droplet of water, $\frac{1}{1000}$ of an inch in diameter, cannot fall in still air at a much greater rate than $1\frac{1}{2}$ inch per second. The resistance is as the diameter.

80. VAPOUR-PRESSURE OF DROPS OF WATER.

Sir W. Thomson showed† that there is a definite vapour-pressure for each amount of curvature of a liquid surface, necessary to equilibrium. It is less as the surface is more concave, greater as it is more convex. Hence precipitation of water vapour will, *cæteris paribus*, take place more rapidly the less convex is the surface of that already deposited. Thus, as Clerk Maxwell has pointed out, the larger drops in a cloud must grow at the expense of the smaller ones.

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* Prof. Tyndall, *Macmillan's Magazine*, March 1869.

† See Proc. Roy. Soc., 1870, and Tait's 'Properties of Matter.'

81. Dryness of the Air at great Altitudes.[*]

Above the clouds, in certain ascents, the observed degree of humidity at

7,000	feet was	64
8,000	„	58
9,000	„	52
10,000	„	52
11,000	„	48
12,000	„	48
13,000	„	43
14,000	„	58
15,000	„	53
16,000	feet was	45
17,000	„	43
18,000	„	21
19,000	„	36
20,000	„	33
21,000	„	32
22,000	„	21
23,000	„	16

The intensity of radiation and evaporation at these last altitudes would be very great.

82. Observations on Dust Particles at Ben Nevis.

Preliminary Notes on Observations of Dust Particles at Ben Nevis Observatory. Angus Rankin.[†]—"Fog is mostly observed when the temperature is below 32°, and [wet] mist when it is above that. In fog there is usually a considerable amount of dust, in mist very little. This difference in the dustiness of a cloud explains to a certain extent why it should be wet or dry, at least when the temperature is over 32°, for in a fog the watery vapour in condensing has more particles to condense on, and consequently the particles of fog are smaller, and on meeting an object with a higher temperature, instead of wetting it, the object dries them up by parting with some of its heat. On the other hand, in a mist, the particles of dust being few, have more water condensed on each, and so are larger, and do not readily evaporate with small increments of heat. It is sometimes observed, and this too when the number of dust particles measured is extremely small, or even nothing, that the air is surcharged with vapour, if such a condition be possible, and that then, for the want of dust particles to form on and so to fall in drops, it simply condenses on all exposed objects direct from the air. This is the most wetting condition of the air . . . every post and rope seem running with water. . . . If the temperature is below 32° in such weather, *a thick coat of transparent ice* * forms on all surfaces in a very short time. This condition is usually experienced when over a moist low current we have at Ben Nevis, or immediately over it a cold upper current. There is usually a great thickness of cloud below us and this traps the ascension of dust, while with the warm moist air and the cold overlying current (usually from a different direction, and sometimes an outflowing one) there are the essentials for condensation without the means—the dust. . . . Mr. Aitken has shown that, in calms, the dust particles are much more numerous than where there is considerable motion of air. Many thunderstorms arising in calms would thus occur in areas of maximum dust. All our lowest values (of dust) have been obtained when a thin [wet] mist enveloped the top."

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[*] See Wells on 'Dew,' and Report of Brit. Assoc., 1862.

[†] 'Journal of the Scottish Meteorological Society,' Third Series, No. VIII.

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* The italics are mine.—[R. R.]

It is observed * that "when the number of dust particles noted is extremely small, or even 0, the air is surcharged with aqueous vapour, if such a condition be supposed possible, and that then, there being no dust particles to serve as nuclei on which the vapour might condense, it simply condenses on all exposed objects direct from the air. This has been found to be the most wetting condition of the air, a few minutes only being sufficient to give the observer a thorough soaking. Every post and rope seem running over with water."

83. SILVER THAW AT BEN NEVIS.†

During the period 1885–90 there were 198 cases of silver thaw, nearly all in the winter

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* 'Report of the Committee on Meteorological Observations on Ben Nevis,' 'Report of the British Association,' 1891.

† Journal of the Scottish Met. Soc., Third Series, No. 8, 1891. 'Silver Thaw at Ben Nevis,' R. C. Mossman.

months. Their total duration was 873 hours. Cases were rare with a temperature below 27°. The lowest temperature was 18°. Ninety per cent. were with a temperature between 28° and 31°·9. Silver thaws took place with west wind, and a descending warm moist current. The number of dust particles in the air was very small on these occasions. Objects sometimes became covered with several inches of solid uncrystallised ice. The screen was often badly choked with ice. The rain froze on observers' coats, gloves, and faces.

84. SILVER THAW AT RICHMOND, 1868.*

On January 11, 1868, the temperature was 32° at 8 A.M., bar. 29°·96, wind south, force 2, and there was a little snow early. The day was rainy till 6 P.M. The rain lasted without intermission until the evening. There was no hail or sleet. The rain on touching any terrestrial object was immediately turned into ice. Thus the trees and hedges were soon covered with a sheet of ice, and glistened with a coating of ice and icicles. Roofs, benches, gates, &c., all had long icicles hanging from them, and as the rain continued the icicles increased in size. The grass and earth were in some parts sheeted with ice. The windows of houses and carriages were thickened with a transparent icy layer, the rain freezing on touching the glass. The trees were weighed down with ice until the evening, when a thaw set in, and the ice fell with a loud noise, the air being calm. The thermometer remained at 32° during the day. At 9 P.M. on the 10th the thermometer had been 30°, the wind east, with high barometer, 30°·25. On the 12th the temperature was 37°, with south-west wind and rain. On the 14th the temperature was 49°, after a heavy south to west gale. This silver thaw evidently depended on the supervention of a warm moist southerly current, and the rain must have fallen through a stratum of air below the freezing point before reaching the air near the ground with a temperature of 32°. The rain was sufficiently cold to freeze immediately on objects very slightly below, or at, or above the freezing-point, the act of congelation apparently not giving out sufficient warmth perceptibly to hinder the process.

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* 'MS. Notes by R. Russell,' January 1868.

85. SILVER THAWS IN GERMANY.

Müller noticed rain and 'glatteis' in January, 1845, when the air and ground had been above 0° C. The rain froze instantly, and even umbrellas brought out from a warm room were quickly covered with ice half a line thick.*

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* On Jan. 22, 1867, in London, "Rain falling on an open umbrella covered it with a sheet of ice. After the rain the temperature rose very quickly." (Mr. Curtis, Quart. Journal of the R. Met. Soc., July 1889.)

86. CONDENSATION, DUST, AND ELECTRICITY.*

With regard to the fine dust with which the air is pervaded, Mr. Aitken observes: "My experiments on cloudy condensation revealed the fact that there are enormous multitudes of particles so small that the concentrated light of the sun does not reveal them. . . . Hundreds are concentrated into every cubic centimetre of air." It appears that before a thunderstorm the dust particles are more numerous, or aggregated, as it were, in clouds. In condensing masses of warm vapour at high altitudes there would thus be portions where dense precipitation would readily take place, and other portions, where, in the absence of dust, it would only take place on the introduction of liquid or solid particles.

Recent experiments by Mr. Aitken led him to the conclusion that the increase in the density of a jet of steam when electrified is due to an increase not in the size of the drops, but in their number. The electricity seems to prevent coalescence of the minute drops. Mr. Bidwell's still more recent experiments † tend to confirm Helmholtz's theory that the phenomenon is due to the recombination of dissociated oxygen and nitrogen molecules.

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* Proc. Roy. Soc., 1887; also vol. li. p. 408, Aitken.

† 'Quarterly Journal of the Royal Meteorological Society,' July 1893.

CHAPTER VI.

SUMMARY OF CHARACTERISTICS OF HAILSTORMS AND HAILSTONES.

1. HAILSTORMS occur chiefly in the temperate zones. In the tropics they are rare on the plains and on low ground at a distance from hills, but are common within certain small areas, especially in the hills above 1200 feet high, also where high mountains are not very distant, and where the air is charged with moisture in the hot season. In the temperate zones the conditions of frequency are somewhat similar. A moderate proximity to high mountains, an inland situation, exposure to great heat, and varying winds are favourable to the incidence of severe hailstorms. Wide plains such as those of North America, where great heat in the lower air co-exists with a cold and rapid upper current, are subject to tornadoes, in which very large hail frequently falls. In the arctic regions hail is almost unknown. In mid-ocean it is uncommon. Hailstorms are generally local, that is, they fall upon very small areas.

2. Great hailstorms are distinguished by conflicting currents of air, by the heat and

sultriness preceding them, by excessive display of lightning, by a sudden strong wind, by the great height, massiveness, compactness, towering form, and darkness of the clouds, and often by the cumuli being in distinct masses at different heights. The barometer remains steady, or rises, or falls, so that the resultant effect of hailstorms on the pressure of the lower air may be counted as nil. Temperature is commonly some degrees and often many degrees lower immediately after a hailstorm than before it. Electric action, as shown by the electrometer, is exceedingly strong and varying during a hailstorm. In elevated positions electricity is given off from all pointed objects in visible and audible form.

3. Most hailstorms occur between 11 A.M. and 5 P.M., but some of the most severe in the middle of the night.

4. In Europe, hailstorms occur most frequently during the late spring and in summer; in the tropics and Australia during the hot season. Small hail and sleet is most common in winter and spring in England.

5. Hailstorms are very common on high mountains up to about 19,000 feet, which is the greatest height to which observation has extended, so that it is nearly certain that falls of hail, though not of very large size, are common at a much greater altitude.

6. On high mountains when large hail falls

there is often a dense mist or cloud, and there is some evidence that as the hail falls through this cloud it increases in size.

7. On high mountains, and in very cold dry weather, precipitation occurs mostly in the form of fine needles or crystals of ice or of dense pellets of soft hail or hard snow.

8. The commonest forms of hailstones are the following:

(1.) Pyramidal, top-shaped, or conical, with a rounded convex base. The base is generally composed of clearer and harder ice than the apex. Sometimes there are layers of ice alternately clear and opaque, both axially and radially from the axis. The conical form is very common in England.

(2.) Spherical, partly clear and somewhat opaque, or sometimes wholly clear. Sometimes, and probably most frequently, the nucleus is nearly opaque, like a nodule of snow, and is surrounded by clear ice which in its turn is encompassed with several rings alternately clear and less clear. Occasionally the exterior is found to be crusted with snow or frost. The round hailstone appears as a rule to be constructed radially from the centre and contains a number of small vesicles of air elongated in the direction from centre to circumference. Even rays, as if extended from a simple snowflake, have been observed.

(3.) In certain hailstorms some of the large round hailstones have been found encrusted with very remarkable crystals of rather large size of a regular hexagonal type; these were bedded in the hailstone so as to leave a hollow on removal.* Other hailstones have been found covered with smaller crystalline growths with blunted ends. Flattened spheres, thinner in the middle than at the edges and dinted irregular spheriods, have been observed.

(4.) Ellipsoid or lenticular. These forms are not at all uncommon in the greater falls, and are often compared to eggs. They frequently have a visible radial structure similar to that of the round hailstones, and may have a very rough coating armed with points.

(5.) Irregular and angular masses of ice of various shapes. These seem to fall only in the heaviest hailstorms. Many other shapes occur, but deviations from the above types are rare.

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* Like the matrix, as it may be called, these crystals have been seen to present an agate-like structure.

CHAPTER VII.

THE DEVELOPMENT OF A HAILSTORM.

Let it be supposed that on a summer morning with a gentle south-west wind, bright sunshine, and considerable humidity of the lower air, upward currents of the ordinary type are set in motion; further, let it be supposed that either variable currents, or calms, prevail between 6000 and 40,000 feet, or that the wind at altitudes above the surface wind blows from west-south-west, west, west-north-west, or north-west, a very common condition in the northern temperate zone. Let the temperature at midday decrease more rapidly than according to the normal rate with altitude, and let the differences between adjacent strata or blocks of air be greater than usual.

All these conditions are such as may easily co-exist, and in fact often do co-exist in spring and summer in this country. Recent experiments on the Eiffel tower have shown that, contrary to expectation, the velocity of the wind in summer often decreases with altitude.

Owing to differences in humidity and temperature near the surface, the sun, after shining for some hours, will raise a number of columns of heated air, such as on the majority of fine days, when the air is not very dry, dapple the face of the sky with small cumulus clouds. Cumulus clouds of this kind are certainly caused by the irruption of shafts of heated air from near the ground into the upper air, for they commonly appear only over the land, and may often be seen from the south coast of England beginning to form a few miles inland, while the sky remains cloudless over the Channel. I have also seen on two occasions, when the sky was cloudless, a column of heated air and smoke from a heath fire ascending to a great height, and terminating in a small cumulus of the ordinary type.

In the state of weather above described a number of warm and rather humid currents stream upwards through the superincumbent air, and increase in strength with the increase of the sun's power. The less stable the equilibrium, that is the colder and heavier the upper air compared with that which is near the surface, the stronger will be the upward flow; the updraught will occur at places which are most favourably situated owing to maximum heating below, and to masses of air at minimum temperature at certain high levels. It will be observed that on a morning combining the above conditions the cumulus clouds continue to grow in a somewhat ominous manner, that their edges are hard and rounded, that they are more deeply shaded than usual underneath, that sometimes they are composed of several layers, that when near the horizon they present towering forms of a pyramidal, turreted, or irregular conical shape invading the clear sky, and that the upper parts appear to move more slowly than the lower, or even to be immovable unless watched for some time. Two suppositions have been made above as to the directions of the upper currents: if these are moving from a different point of the compass from the lower wind, and in such a manner, for instance, that at successive heights the direction has less and less of a southerly component, the successive bosses of cloud in a cumulus overhead will be seen moving more or less in accordance with these directions, but to be very considerably disturbed by the action of the column of ascending air and of the cloud mass itself. The interior of such a cloud we know to be cold, often colder than the air immediately above and below it, and the effect of its shadow may be sufficient to cause a down draught of a column of cool air nearly parallel to the ascending shaft. As the sun is shining obliquely, the down rush might be expected in the morning to follow, and in the afternoon to precede, the ascending column, and the shower, if any; whether this is actually the case in most instances I do not know. We must bear in mind that the cloud representing the spreading capital of the column is always changing as it moves on, condensing freshly supplied vapour into the visible form, and losing at its edges that which had already condensed. The apparent movements of portions of the cloud are therefore very deceptive; and even the existence of violent internal motion is usually hidden by the dense masses below. In favourable situations, however, it is usually possible, by viewing the clouds through branches of trees or overhead wires, to separate the movements of portions of cloud at different elevations. These movements are in general slow, and present no plain evidence of any strong whirl or updraught.

From conditions like those described a hailstorm may be developed in the following manner. The upper currents are dry, cold, and for their level heavy; the lower current is moist, warm, and for its level light. The escape air from this lower current may ascend somewhat rapidly, as through a chimney, to the high level, or in a large heated mass after the manner of a fire-balloon, expanding and cooling by expansion till in the visible cloud it is reduced below the dewpoint. A descent meanwhile of cold air into lower levels takes place, but is, of course, not observed below the line of visible condensation, for the descending body of air has its temperature increased by compression, and no lower cloud may be formed to mark its progress. Sometimes, however, its descent is betokened by the mammelated or festooned cloud, which is unmistakable in its significance of a descent of cold air, but often occurs without precipitation, though very threatening in aspect. It is remarkable that in most thunderstorms or hailstorms there is little or nothing in the lower air to indicate the existence of the ascending column of warm air. The flow from the neighbourhood of the earth into the upper region in these cases cannot be rapid, though it may be large. Probably in many cases the inflow towards the base of the cloud covers a wide area, say of several miles at the earth's surface, and is betokened by calms and variable airs. At 2000 or 3000 feet the inflowing currents will have acquired a strong upward movement within an area of much smaller diameter. Standing on an eminence of 1000 feet or less, an observer may sometimes see shreds of cloud at about the same altitude moving in opposite directions, below the base of the black cloud which constitutes the lower part of a small thunderstorm. As soon as the ascending mass of warm air reaches a level where, by its own expansion and by contact with colder masses, it is sufficiently cooled, its abundant vapour is largely condensed in the form of a thick black cloud. A fresh motive power for ascent is now brought into play.

A cubic foot of air at 70° is saturated with 8 grains of vapour. Let it be supposed that a cubic foot of air at 70° on a sultry summer's day contains 6 grains of vapour. Let that cubic foot of vaporous air rise to a height of 9100 feet, and let it be supposed, for convenience, that none of its vapour has been condensed until that height is reached. At that height of 9100 feet its temperature will have been brought down to 30°, for ascending air is reduced by 1° temperature, for every 182 feet of ascent, so long as its vapour remains in the gaseous form. Now, since at the temperature of 30°, a cubic foot of air can only contain 2 grains of vapour, 4 grains of vapour must be condensed to the liquid form. The condensation of 4 grains of vapour raises the temperature of 1 cubic foot of air 29°, so that the original cubic foot is now saturated at 30°, holds only 2 grains of vapour, but 4 grains of cloud particles, and is raised to a temperature of 59°, at which a great part of the cloud globules is reconverted into vapour. In this calculation the change in volume by the opposing effects of expansion and of cold has been neglected. At 9100 feet, then, we have the cubic foot still at a high temperature, 59°, much above that which usually prevails at such levels. In reality, of course, the precipitation of vapour begins suddenly at a lower level than that assumed, and as the air continues to rise while being heated by the condensation of its own vapour, the process of condensation goes on proportionately. The ascending force is evidently much increased where condensation occurs: the primary upward current is set in motion by conditions of unstable equilibrium, but tends soon to exhaust itself owing to the reduction of its temperature by expansion in ascending being greater than the decrease of temperature with height in surrounding strata, except in abnormal conditions, and the ascent would soon cease, but that condensation of vapour then comes into play, and soon raises the temperature of the ascending column above that of the strata of corresponding height. The upward rush therefore continues until, at a low temperature and great height, nearly all the vapour of the particular volume of air has been deposited in the form of cloud. The precipitation is rendered greater and more rapid by two causes; first, the mixture of the column of ascending air with cold air, especially as it spreads out at a high level, and secondly, by radiation from the top of the cloud into space, and the consequences which result from this quick radiation. It has been stated by some meteorologists, that the rainfall produced by mixture of masses of air at different temperatures cannot be very heavy. A column of air at 70°, mixed with another at 30°, both columns being 10,000 feet high, would not give more than about 0·4 inches of rain.* But we have to consider that in a thunder or hailstorm columns or masses of air of different temperature are being *continuously* mixed and reinforced. Moreover, in great storms the height of the cloud may be 20,000 feet, or more. And the top of the cloud may be the capital of a column of warm air impinging on a horizontal current of very low temperature, dry enough to permit free radiation. Thus the warmth produced by condensation would, at the top of the cloud, be both radiated and carried away.

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* Scott's 'Meteorology'; Abercrombie's 'Weather,' see Appendix D.

We may here observe that the results which might be expected to follow the condensation of vapour in natural conditions do not commonly occur. On a fine night, with clear sky, cold air descends from the slopes of hills and collects in valleys, and a stratum of cold air rests upon level ground. If the air be rather moist, and the temperature sink below the dewpoint near the ground, a fog is formed. If it be dry no fog is formed. The condensation of vapour in the first case might be expected to produce an elevation of temperature, or to maintain the low stratum at a degree not much below that of the air above it. But, as a matter of fact, both the ground below the fog and the foggy air itself sink considerably below the temperature of the clear superincumbent stratum. When a dense fog covers the ground, and extends to a moderate height, say between 20 and 200 feet, the temperature of the fog is often from 5° to 10° lower than that of the air above it. Such differences do not occur when the air is too dry for fog to be formed, so that the result is paradoxical. With increase of fog, and increase of temperature by disengagement of latent heat, temperature, instead of rising, falls. The lowering of temperature is probably due to the increase of radiating power brought about by the formation of small water-globules, which are excellent radiators of obscure heat. A film of the thickness of about $\frac{1}{100000}$ of an inch, absorbs about 9 per cent. of the low radiant heat which falls upon it.* A fog-particle would radiate into space the greater part of its heat of condensation in less than a second, and by radiation would continue to draw heat from the neighbouring particles of air, while not receiving any appreciable heat by radiation from the superjacent air. Much more rapidly would the watery and icy particles, on the summit of a high cloud, part with their heat through the dry air above them.

If the air near the ground be nearly calm, or if only a light wind be blowing, storms fall heavily upon certain places, and do not move rapidly; in fact, they often remain about the same spot till their force is expended. It does not often happen that a storm passes quickly across the country while the lower air is calm. When, however, a strong steady wind blows, the storm may travel at a great speed, corresponding with that of the wind.

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* Trans. Brit. Assoc., 1880, R. Russell.

Often a violent wind accompanies the hailstorm in otherwise calm weather, and in that case the storm may move at almost equal speed with the wind; but, on the other hand, some storms of great intensity have remained for a long time apparently almost stationary, and many move slowly, unaffected by the blast along the ground. In the central area beneath the storm either calm prevails, or variable and gusty winds. North and south at some distance, the characteristics of the southerly and northerly quarters of small irregular cyclonic movements may be noted, or the storm may occupy a position in a barometric trough.

Taking a vertical section of the storm system passing through the axis, it seems nearly certain that the thermal conditions at several points would be somewhat as follows: near the axis and near the ground, high temperature; in front of the storm, high temperature; in the rear of the storm, low temperature; in front of the axis, up to a great height, high temperature; in rear of the axis, up to a similar height, low temperature, and lower in proportion to height. For a long distance on each side of the storm's advance, and beyond its actual extent, conditions to some degree similar to these often prevail, and the air in front is warmer than that behind it. On the other hand the changes of temperature belonging to a storm are often merely local.

The ordinary cold of the air in summer, at a height of 25,000 feet, or less, may be sufficient to produce a hailstorm wherever a warm current invades it from the lower air. But in order to produce a hailstorm of uncommon magnitude or intensity it seems necessary that masses of air widely differing in temperature and moisture, and possibly in electric state, should be suddenly and intimately mixed. The hailstorms of the Andes are examples of disturbance caused by recurring diurnal conditions; the great hailstorms of the hills and northern parts of India, and of France and England on rare occasions, are examples of abnormal atmospheric contrasts. The usual lowering of the temperature for a short time after a hailstorm even of small intensity signifies the descent of a very cold block of air from a high level. That this block, wedge, or mass, is not commonly of great volume or extent seems likely from investigations of the temperature on days following thunderstorms. In most cases the reduction of temperature does not extend beyond 24 hours.* Suppose that the temperature falls 8° soon after a hailstorm; this may be taken to mean that at a height, say of 15,000 feet, the temperature is much more than 8° below normal, for the thin air descending from that level would have been mixed, before reaching the earth, with a larger volume of warm lower air, and indeed only a small proportion can reach the lowest stratum. So much as does reach the earth is, of course, raised in temperature by the compression undergone.

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* Yet the hailstorm may signalise a merely partial and temporary escape of air from a widely extended cold stratum at a high level, and in that case hailstorms are likely to recur at several points over a wide area.

Glaisher and others have noted a temperature of 15° F. and less at about 15,000 feet in summer; it is therefore very probable that in the condition which gives rise to hailstorms the temperature at this level may be below 0° F., in June, July, and August. The period of the year, the time of day, and the localities at which hailstorms are most common or most severe, all favour the conclusion that either the mixture of warm moist air with cold air, or else the sudden elevation of a mass of warm moist air, is the necessary condition for the production of hail.

In these conditions imagine the storm system described above to develop. The heated ascending air in front of it, and may-be on several sides of it, on meeting with the cold mass, which may extend from say 3000 or 10,000 to 20,000, or even 40,000 feet, loses some of its vapour in rapid condensation, and sometimes part of the least warm air from below may flow along underneath the advancing cold mass, helping to form the ominous black cloud so characteristic of the first part of a thunder-shower. The rear of the rising mass is soon caught by the downdraught of cold air, driving obliquely towards the ground to take the place of the updraught in front, and the aspect of the ragged edges of the back of this heavy and low cloud marks the approach of the stormy wind and the vehement onset of hail which follows. More commonly, perhaps, the black lower cloud is produced where the junction and mixture of the two masses of air at different temperatures is most rapid and forcible, and may be considered as resulting as much from the down-thrust of cold as from the ascent of warm air. This cloud is distinctly much lower, and apparently separate from the grey and uniform stratum which often succeeds it as the first part of the storm passes over. The termination of the black cloud is the termination of the first mixture of the meeting currents of specially warm and of specially cold air, and the grey, more uniform stratum signifies the descent of a layer or wedge of cold air from a very high level, to take the place of air which had ascended from low levels in front of the storm. This layer of descending cold air is reinforced by the outflow from the top of the column of warm air, which, as it rises and spreads out at a great altitude, sinks to a low temperature in consequence of its expansion and of free radiation from its condensed water particles. At the altitude reached by the tops of storm cumulus, say 20,000 or 30,000 feet, radiation is exceedingly rapid, owing to the low humidity of the overlying air. The outflowing air at the top of the column tends to take the place of the sinking stratum of cold air, and by the rapid cooling of its remaining supply of vapour, also probably by its electrical differences from the layer over which it moves and with which it mixes, contributes to make this part of the storm, which immediately follows the black cloud, the source of the heaviest hail or of the heavy rain, which, in such a storm, is in fact usually melted hail. Since large hail takes at least three minutes in falling from the high cloud, it is probable that the real source of the heavy hail is often directly over the black cloud which has passed over. Much hail in fact comes from the place of mixture and contact of the rising and falling air masses at a high level. The cooling of the lower air and the passing away of the circulatory system of the storm gradually restores equilibrium; the high grey cloud becomes thinner and lighter in colour, and the rain, though often continuing till the last edge of stratiform cloud passes overhead, diminishes and abates. On looking at the storm cloud from some considerable distance after its passage, there is usually great difficulty in making out any features or movements significant of the working of the system which brings about so great a disturbance. At no time, in most cases, is there obvious evidence of any whirl or cyclonic eddy in the clouds, or of any rapid upward or downward current. Masses of cumulus, overtopping cumulo-stratus and shading into it below, and surmounted sometimes by cirrifying fibrous crowns, give unmistakable proof of mighty puffs and streams of vaporous air invading the upper region. But these masses, with their many rounded tops, impress one with their apparent solidity, fixity, and compact grandeur, somewhat in proportion to the heaviness and intensity of the downpour beneath them, or to the magnitude of the local vertical disturbance, and afford very poor evidence as to the character of the circulation of air between them and the ground. They are only formed where either rapid chilling by expansion takes place or where masses of air of different temperatures and humidities are mixed. Any one who has seen ordinary waterspouts may have noted that scarcely any, if any, commotion or extraordinary appearance in the clouds can be observed, beyond the dark funnel and stem or pipe connecting them with the sea, and in the close neighbourhood of small whirlwinds there is usually a similar absence of visible rotation in the clouds. Yet in these phenomena it is quite certain that a violent eddy is at work in the clouds, and that warm air is rushing upwards from the sea, while colder air is descending above and outside the capital of the column. The movements of dark lower clouds are very difficult to discern when the background also is dark. In a heavy hailstorm the column of ascending air and vapour is much larger, the view from below of the upper clouds is hidden by the lower clouds, and of the lower clouds by the falling rain. Where, however, the precipitation is not large, the storm stationary, and where a few pieces of scud cloud happen to be formed in the air not far from the ground, the darkest cloud will be found, in tolerably calm weather, to occupy a position directly over the base of the ascending column, while hail falls from the whiter and very high cloud on the edge of the densest mass. A rapidly progressive hailstorm does not give these opportunities of observation, and its circulation can hardly be so regular, owing to the variety of conditions encountered in the passage. Yet such a storm may exhibit remarkable persistence. The double storm which passed over France in 1788 was probably an instance of a circulating system of uncommon magnitude.

A hailstorm is followed by great clearness of the atmosphere, and in a smoky town all smoke seems to vanish; it is first drawn upwards by the ascending current, as may be seen from a neighbouring height, and after the storm the clearness remains for some time, by reason not only of the precipitation of dust, but of the large amount of fresh air descending from above.

A hailstorm, then, is commonly caused by the ascent of a large body of warm and humid air into a high region where the air is cold and radiation rapid, and by the simultaneous descent of cold air as the outflow from the column of ascended air takes place at a great elevation. In the greatest hailstorms, the circulation is generally tornadic, or whirl-like in character; a mass of very warm air rises rapidly to a region of great cold, air flows in horizontally and upward from several directions in the lower levels, and a mass of very cold air consequently sinks over the same area. Many hailstorms result from the ascent of warm humid air and the descent of cold air without anything like a true eddy, except what may be incidentally caused by the rise of the column of air, and these hailstorms may be regarded as circulating systems on a vertical plane. Storms of this character occur in the mountains of Jamaica and of Natal, and in the Andes,. by the heating of the air on their slopes and by the wind, either from the sea or from heated plains, flowing up their sides and spreading out into the colder air at a height. A similar vertical circulation and consequent precipitation may be caused by a warm current of air impinging on a mass of air moving in a different direction, and being forced upwards as if the opposing mass were a solid surface. The hailstorms said generally to accompany tornadoes are the result of violent whirlwinds, which forcibly project quantities of moist air, rapidly cooled by expansion, into upper strata which are often at a very low temperature. The expansion of the interior reduces the temperature of the condensing and congealing moisture, and as the force of the updraught is sufficient to carry the drops and pellets to a great height, the hail which falls on the borders of a tornado is sometimes very large.

The manner in which hail is produced and increases to a size of several inches in diameter has long been a problem, and has not been much illustrated by such atmospheric disturbances as have been above described. But in the light of recent observations and discoveries all difficulty in accounting for the formation of hail even of the largest size may be overcome. Let us take the case of a hailstorm of the most severe character, such as occurs in the northern parts of India, and sometimes in Europe. The force of the ascending current, due to the upsetting of the unstable equilibrium, is sufficient to carry large masses of humid air into cold strata at a great elevation. The expansion of this ascending current produces, between a middle and a very high level, a dense precipitate of minute globules of water, so thick as to exceed in opacity the densest fog on the surface of the earth, composed of particles on an average larger than those of an ordinary cloud, and of various sizes.* This cloud extends for 2 or 3 miles at least vertically, and perhaps as much or less horizontally. The lower part of the cloud has the appearance of nimbus, the upper part is a towering cumulus composed of a number of rounded tops, of which the highest sometimes terminate in cirriform crowns. These tops, chilled by the expansion of ascent, by free radiation, by evaporation in the dry air, and by their encounter with strata far below the freezing point, cannot maintain their particles in the liquid state. Experiment in the laboratory and observation in natural conditions in the open air, have proved that minute portions of water may preserve their liquid state when the temperature is lowered down to 20° F. below the freezing point, and more. Agitation, the touch of a solid object, and above all of a crystal of ice, the shock of an electric discharge, or the further lowering of temperature may then determine solidification. In the highest part of these clouds the great cold of the air, with radiation, is sufficient to turn some of the water-globules, and especially the larger ones, into crystals of ice. Once commenced, the process tends to accelerate with great rapidity. The fine spicules or crystals of ice fall slowly downward, and as they fall, attach to themselves every particle of water with which they come in contact. These are all below the freezing point, and the heat of solidification is rapidly lost by contact with the air and radiation to the cold surrounding mass. The latent heat of congelation of a droplet of water attaching itself to the extremity of an ice-needle, need not, as theory is apt to assume, become sensible in the frozen droplet, but is dissipated almost instantaneously owing to the enormous number of cold particles of air meeting it in its fall, and to the radiative quality which water and ice are known to possess. When small drops of water, below 0° C., are thrown upon earth or ice several degrees colder, solidification is almost instantaneous.* As the spicule falls it becomes heavier, falls faster, and develops one of the beautiful forms of hexagonal crystal manifested in snow; or else, if it encounters a dense cloud or larger water-particles comparable to very fine rain, it grows larger at the base than on the top, and accumulates semi-opaque ice enclosing numerous air-bubbles. In the first case, if it remains as a snow crystal for some time, its rate of fall is not great, it grows slowly in moist transparent air, and when passing through clouds accumulates more cloud-particles until it forms a big flake, which then, owing to increased mass in proportion to surface, falls more rapidly. Meanwhile the larger particles of water lower down have increased in size by absorbing many of the smaller, owing partly to their smaller surface tension, and this increase of size may proceed similarly to that of drops of dew on an unwetted surface. The phenomenon of glatteis proves that drops even so large as ordinary rain-drops may exist below freezing temperature without solidification until they touch a solid object. The snowflake encountering multitudes of droplets of various sizes attaches them to itself, and since they freeze in more compact form than smaller cloud-particles and ice-needles, these soon add much to the rate of descent. Three causes of aggregation or growth have been so far taken into account: (1) the solidification and attachment of cold droplets touched by ice; (2) the tendency of large particles of water or ice to attach smaller particles to themselves owing to difference of surface tension; (3) the encounter of many more particles by a large drop or flake than by a small one in the same time, owing to its larger surface and to its more rapid fall. We may now allude to two other influences tending to the same effect; one is the smaller vapour tension of ice in the presence of water of the same temperature, and the other is electricity.

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* The water-globules resulting from a sudden mixture of warm and cold air are much above the average size of the particles of clouds and fogs.

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* The dissipation of the heat of congelation is of necessity more rapid when the smaller droplet of a cloud attaches itself to a snow crystal in the midst of a vaporous medium much below the freezing temperature.

The former probably plays a very small part indeed, and may be neglected as inappreciable. The importance of the latter is very great. Equal, strongly-electrified drops repel each other; moderately electrified drops attract each other. Moreover, the larger drops electrically attract the smaller ones. Every large increase in the size of the drops due to this and other causes leads to a large increase in the tension of the free electricity surrounding the drops; for the surface of a drop is increased at only half the rate of the volume, and the electricity resides wholly on the surface. There will thus be a continually increasing amount of free electricity in the cloud, and a variety of distribution according to the size of the drops. A potent cause is in this way added to the others which favour agglomeration. Electricity manifests itself very strongly at the great height attained by the top of the cloud, as observation on mountain summits, and the forms of cirrus, abundantly prove; and the most striking displays of the brush discharge, or St. Elmo's fire, always occur during a fall of hail or granular snow. Hailstones and snowflakes, even towards the bottom of the cloud, often run over with electric discharges, and every object emits sparks from its extremities. We may assume, therefore, without hesitation, that electricity comes early into play in promoting the aggregation of particles. Already in the upper part of the cloud it would be at work in causing the smaller particles to be attracted by the larger ones, and lower down its influence would be stronger owing to the increased difference between the size of the snowflake, pellet, or hailstone and the size of the droplets of the cloud, and to the increased electric attraction continuously produced by agglomeration.

Balloon observations have shown that at

heights from 5000 or 6000 feet up to the highest level attained, 37,000 feet, strata of air exist at temperatures and humidities differing greatly from the normal or mean and from each other. The air up to 40,000 feet is in fact often made up of masses which present the most unexpected and extraordinary variations. Mr. Glaisher has stated that he never ascended to a great height without passing through several different currents of air, and he also recorded the important observation that when at 37,000 feet above the earth cirrus and stratiform clouds were still much higher. On one or two occasions he passed through clouds almost continuously for 20,000 feet, and on other occasions the balloon traversed spaces alternately cloudy and clear. Observation of the clouds gives the strongest reason for assuming that the last named condition prevails immediately before a hailstorm. The clouds occupy successive levels up to a great height, are sharply defined, and do not move uniformly. They appear to be quite separate at different levels, and do not mix with others. The edges are so clear-cut that the hail or heavy rain begins and ends quite abruptly, and if the downpour is stationary, as often happened in the summer of 1889, one field may be subjected to torrents for several minutes while a field adjoining has scarcely any rain. I have known instances of sudden spurts of hail from patches of high light-grey clouds of a cirro-stratus character without nimbus or cumulus, and separated from each other by sharply defined spaces. The hard rounded appearance of cloud edges occurs also in, or immediately before, heavy gales or squalls when the wind is veering to west or north-west, and since observations at sea and on mountains show a high development of electricity in the clouds at these times, the appearance is almost certainly in these cases also connected with electric action as well as with rapidity of condensation. A sudden change of wind from south-west to north-west in autumn or winter is frequently marked by a storm of heavy rain or snow, and by thunder and lightning, the clouds simultaneously hardening at the edges. In fact, wherever condensation suddenly occurs by the mixture of currents at different temperatures and humidities, free electricity is developed, and in the higher regions this electricity seems to increase the coherence of the cloud. Laboratory experiment corroborates this view, for it is found that moderately or slightly electrified droplets attract each other, and that the surfaces or edges of conductors such as clouds and saturated air acquire a stronger charge than the interior.

It is probable that the clear spaces between clouds through which hail falls are often in a condition of super-saturation, for they are surrounded by dense clouds which have intercepted dust particles, and may have electrically attracted or aggregated the dust in their neighbourhood. The condition prevailing must often be that described as leading to deposition of clear ice on all exposed objects on high mountains; a nearly dustless stratum, oversaturated, has above it a stratum of much colder air, and precipitation does not take place in the warm stratum owing to absence of the means, dust or solid objects. In thundery weather there is usually excess of dust in the lower air; this air, in ascending, condenses vapour largely, is cooled to a low degree at a great height, flows out over the warmer air of the low levels, and the cloud formed precipitates rain or hail from its upper ranges. Dust is thinly distributed in the high atmosphere, and the transparent strata lying over heavy clouds would be comparatively nearly dustless, owing to the filtering action of copious condensation below. The hail, therefore, in passing through these clear spaces, determines deposition of vapour upon itself in solid or liquid form; if liquid, the cold of the hailstone and of the surrounding air speedily congeals it to a coating of clear ice like that formed on a pond when the air is transparent, except that more air bubbles would generally be inclosed. The most opaque parts of a hailstone are formed in thick clouds, and the appearance of the ice resembles that formed in a fog on a lake or pond.

There is some reason for entertaining the opinion that the effectual latent heat of condensation in super-saturated air, and the latent heat of solidification of very cold water-particles may be somewhat less than the normal amount resulting from condensation and freezing. It seems possible that a condition resembling that of vapour made viscous under pressure, as described by Andrews, may be attainable by vapour accumulated without the ordinary means of condensation in air. As regards congelation, it is noteworthy that hailstones usually consist of soft ice interspersed with air-bubbles, and that this ice has been formed from cloud-globules cooled down, say, to 10° or 20° F. below the freezing-point. Whether the molecules of water may so arrange themselves as to part with a portion of their latent heat before solidification, there appears to be no information from experiment; but practically the conditions are such as to lead to the quick dispersal of the heat set free on the surface of a hailstone. The conversion from over-cooled water to soft ice, and the exposure of each particle of ice formed to cold surroundings in its rapid passage, must be taken into consideration in estimating the amount of latent heat which on being set free would reside in the hailstone. The amount would be insignificant.

Passing through a cloud of water-globules or very small raindrops, a hailstone attracts them strongly, for their electric charge may be considered nil, owing to the minuteness of their surfaces compared with that of the hailstone. Now, if the hailstone and the globules were dry solid bodies and not ice and water, the hailstone would attract them, and on their touching might repel them again. But since each globule is liquid it is instantly frozen on touching the hailstone, and adheres firmly owing to the force with which it was attracted or encountered. Even if the attracted particles were soft ice they might remain frozen upon it owing to the momentary lowering of the freezing-point by pressure, and to consequent local melting and regelation. The particles electrically attracted and attached to the hailstone would at first arrange themselves according to the original formation of the snowflake or pellet; thus the faint persistence of the six rays in the solid ice may be explained. The rapidity of fall of a large hailstone is sufficient to make the particles which it overtakes into solid ice, as has been pointed out by Reynolds, and paralleled by the formation of transparent ice on mountain observatories while a strong moist wind blew with temperature below the freezing-point. If we assume the hailstone to be half an inch square in surface, and one water globule to be overtaken by it in each cubic half-inch of fall through 15,000 feet of cloud, then the hailstone overtakes and attaches to itself 360,000 globules. The number might very well be larger, for the kernel of the developing hailstone does not pursue a straight path towards the earth. Moreover, in a hailstorm of the whirlwind or tornado type, the hailstone is delayed in its fall by the updraught, which continually drives against it multitudes of cloud particles below the freezing-point.

A snowflake, supposed to be an inch square, and $\frac{1}{10}$ inch in thickness, would, in falling through 15,000 feet of cloud of the supposed density, overtake 720,000 particles. Let these be supposed to be $\frac{1}{75}$ inch in diameter, about the size of a small raindrop, and let the overtaken drops be supposed to be stationary, prevented from falling by a gentle updraught. Then in its fall the hailstone grows to a length of 1·73 inch, plus expansion, by additions on the downward face, and of course grows to some slight extent at least on the edges. If the small cloud-drops are falling at the normal and average rate of 480 feet, and the hailstone falls at the average rate of 4500 feet a minute, the deduction from the above figure of 1·73 will obviously be small, reducing the length of the hailstone say to 1·56, plus expansion. Whichever supposition be taken, and even if the flake or hailstone be long kept aloft by the updraught, it is clear that it has opportunities for collecting an amount of ice upon its surface sufficient to account for the size of large hailstones, provided the cloud be of the stated thickness. Density is expressed by darkness.

In certain stages of its fall, it may exceptionally happen that a hailstone meets a dense throng of raindrops, caused either by a discharge of lightning having immediately before released the cloud globules from a state of high tension, and so permitted them to coalesce, or else by electric action aggregating particles along lines of force, as has been shown in experiments on smoke. It is obvious that icy bodies falling into these cloud-precipitates would grow rapidly in mass, and that we have in the above-named electrical developments one reason for the sudden spurts so characteristic of thunderstorms. A flash of lightning may indicate that water communication of the cloud with the earth is at its maximum, though the downfall may not quite have reached the earth; the redoubled fall of hail, a minute or two later than a flash, may indicate the influence which the discharge had upon the agglomeration of drops in the cloud. It has commonly been assumed that an increase or diminution of hail or heavy rain immediately after a flash or thunder is a consequence of the discharge, and the time taken by hail or rain to fall through some thousands of feet has been neglected. At Pike's Peak, which may be supposed to lie less than 10,000 or 12,000 feet below the hail-forming cloud, an interruption in the downfall, lasting half a minute, follows a strong flash, and then it is heavier than before. The increased fall may here be taken to follow immediately on the release of tension in the cloud. On the low levels a further minute or two at least would pass before the fresh spurt would be observed. A flash between the upper and lower clouds may indicate the setting up of communication between them by rain or hail from the upper cloud, and this downfall would reach the ground a minute or two at least after the flash.

We may conclude that while rapid condensation of vapour in the upper air produces much free electricity, the effect of the electric charge upon the water-particles of the cloud, and thereafter upon precipitation, is twofold, partly inhibiting and partly promoting aggregation and downfall. A strong charge in a mass of equal cloud globules prevents their union and fall, a weak charge favours rain-formation, and to a very high degree when the cloud is pervaded by drops greatly differing in size. Discharges of electricity, and constantly changing electric relations between the different clouds produce the characteristic changes in precipitation. The upper clouds are positive, the lower negative, so that a hailstone enters a negative cloud strongly charged with positive. The result is attraction and rapid growth.

Where hail precedes the rain shower, it may simply signify the swifter fall of the larger body through the air, or the more rapid movement of the upper cloud over the spot, and where the heaviest hail is at the end of the shower, as often happens in India, it may show that the ascensional warm current only reaches the highest region, where congelation takes place, after condensation sufficient to produce heavy rain had proceeded for some time in the lesser altitudes. This condensation itself, by the release of latent heat, might produce a powerful upcast after the commencement of the storm.

In a tornado, it is probable that the largest hail may sometimes have been whirled more than once up through the central part, and out towards the exterior, of the moving column, and may have accumulated freezing rain and snow in both portions; but in general it would appear that frozen raindrops carried up to a great height by the updraught, and falling through dense clouds under the conditions of sudden condensation, might well grow to the observed size in the double passage.

The diurnal fall of hail and the heavy thunderstorms on the south side of the Andes, show that a heated ascending mass of somewhat humid air, projected into the cold of the upper region, is sufficient to produce moderately large hail and abundant liberation of electricity.

The fact that snow often falls from an apparently clear sky, especially in the Arctic regions, proves that by radiation from particles sufficient heat is lost to allow condensation and aggregation. The formation of snow must be very often due to radiation from the top of a cloud, and seems to take place with lighter clouds than are observed with rain. No doubt the difference at the earth's surface is partly owing to the quicker evaporation of a raindrop than of a snowflake in passing through the lower strata. The large hailstone, consisting of an opaque nucleus with rays extending some distance from the centre and surrounded with alternate rings of clear and opaque ice, may be formed by the original nucleus, consisting of a small symmetrical snow - crystal, falling first through an ice-cloud or very cold cloud, and so growing in size, and then through a water-cloud consisting of larger globules, which would be quickly annexed and frozen. The original hexagonal plan would more or less hold its own, while water-particles, instantly freezing and under the influence of electrical attraction, were being added to its mass. The spherical form would probably be acquired where the greater part of the passage in the higher regions was through water-cloud; the discoid form might be assumed where the original crystal or snowflake was large, and fell through a thick cloud of wet snow and freezing globules. The additions to its size in the latter case would be largely at the edges. The alternate layers of clear and opaque ice may be produced by a hailstone falling through successive spaces filled alternately by dense cloud and clear air, and in some cases by dense cloud and by air in which thick small rain would be falling. Although a very cold hailstone falling through very cold moist transparent air is capable of congealing ice upon itself, the process would in most cases not be very rapid owing to the large development of sensible heat.

We have then to assume that hailstones with concentric bands have passed through dense clouds and clear air as many times as they have bands. This supposition is corroborated by the form of clouds seen overhead, evidently sharply separated, and in rounded summits towering above each other towards the horizon; also by the fact that discharges of lightning take place in the largest proportion between the different clouds, which act like separate charged bodies at different levels. The rotundity of some hailstones would seem to indicate that electric attraction, which is equal all round, attached more particles than the impact of the falling body, except in the few instances where the stones had early acquired a movement of rotation. The prevalence of the spherical shape, where the stones are large, favours the view that they are so formed by electric influence. The sphere could otherwise hardly be formed around a nucleus exhibiting six rays prolonged into the clear ice, for the nucleus would grow most by impact on the lower side. The original form of the flake or pellet may largely determine the form of the hailstone, and part of the growth must follow the action of the eddies produced in falling. An original spheroid, whether a frozen drop or a pellet of snow, would be likely to preserve the spherical form throughout; in the one case, the nucleus of the fallen hailstone would be clear, in the other opaque, but there would not be six rays diverging from the centre. Occasionally, large hailstones have fallen which, after the melting of the exterior crust, were clear throughout; these may have been made by the addition of droplets to a frozen drop. The large crystals which, very rarely, project from the surface of large hailstones, are probably formed by the attachment of hexagonal snowflakes to the moist surface at a certain stage of the fall, and by the growth of these crystals by strong electric attraction. The phenomenon requires investigation, for these large ice crystals are produced in a few moments, while under ordinary conditions no large regular crystals of ice are observed in nature. The possibility is suggested of artificially producing fine crystals of other substances from their vapour by rapid movement under electric excitement.

CHAPTER VIII.

CONCLUSIONS.

1. The clouds in which large hail has its origin are commonly at a great height—between 15,000 and 40,000 feet, or higher. These clouds are the result chiefly of expansion and refrigeration of warm humid air, of the sudden mixture of masses of air greatly differing in temperature and vapour tension, and of free radiation.

2. The nucleus of a hailstone consists of a snowflake, pellet, or spicule, which falls from the uppermost cloud. In very cold and rather dry air, spicules, pellets, or minute snowflakes are formed; in a moist and less cold air, large snowflakes may occur. Rarely, the nucleus may consist of a raindrop frozen in falling through a cold stratum, or in ascending through the vortex of a tornado, chilled by the interior rarefaction.

3. The snowflake, pellet, or spicule, is electrified as a result of condensation, and as it falls attaches particles of ice and globules of water below the freezing-point to itself, the particles arranging themselves commonly in a stellate form or concentrically around the nucleus. The variety of

form of the primitive kernel is great, and consequently hailstones of many different shapes may be met with. If the original nucleus is a round snow-pellet, or a frozen raindrop, the hailstone may be nearly spherical; if the nucleus is an irregular hard snow-pellet, such as may be observed to fall in some very cold winters, the hailstone may be of an irregular shape, and owing to the position of the centre of gravity tends to increase and grow spheroidal at the base; if the nucleus is a pyramidal or conical snow-pellet, the hailstone is often similar in form; if the nucleus, when it meets with a dense watery cloud, is merely a straight ice-needle, or a needle with one or two bifurcations (like a good deal of the sleet which fell in England in the winter of 1892–3), the hailstone may be rather long, oval, or irregular in shape; if the nucleus is a stellate snow-crystal, the hailstone will be round, ellipsoid, or conical, and may show the extension of the six rays of the crystal into the concentric zones. The shape of the hailstone is to some degree determined by the pattern of the original crystal, and this seems to depend on temperature, humidity, electricity, and the number of dust particles in the air. The suddenness of mixture of different masses of air is of much importance in producing snow and hail of large size. Moist warm air suddenly brought into contact with cold air produces large irregular snowflakes; these large flakes may sometimes be formed at a great height, and, on falling through dense clouds below the freezing-point, collect sufficient ice to reach the ground as large irregular oval or angular blocks, either by themselves or interspersed among large hailstones of less uncommon size and shape. Large hailstones of this sort may be separated from each other by a distance of several feet or yards, just as large snowflakes often fall very sparsely and unaccompanied by smaller flakes. Crystallisation may be supposed to occur at some points in the upper part of the cloud, and ice-crystals to grow rapidly on the few flakes formed as they fall through a cloud, not competent without such provocation to precipitate moisture. The flake, bearing an electric charge, as it traverses the cloud, collects congealing particles in such numbers as to form an irregular aggregation, occasionally more than an inch in diameter. Such a flake, formed in the upper part of a dense thunder-cloud, and highly charged with electricity, would attach water-particles below the freezing-point to itself at such a rate and with such force as to become a block of soft ice, and its rapid fall would further increase the density and hardness of the ice accumulating on the lower side. In certain conditions, wet snow may be developed at a great height, and may become frozen in passing through a colder and lower stratum. In other conditions, as when cumulus is projected into comparatively dry air, pellets, soft hail, or graupel may be formed. In each of these cases, electric attraction and rapid fall through freezing cloud increase the growth of the nucleus and make a hailstone.

The ordinary top-shaped hailstone is produced by the lower side growing more quickly than the upper, as it comes into contact with more particles; and since the impact is most forcible on the lower side, the ice of the spheroidal base is the hardest.

Large hail may not infrequently be caused by snowflakes or soft hail falling into dense cold cloud in the central part of a tornado, and being whirled upwards so as to traverse the thickness of the cloud more than once. Ejected at the top of the column this hail would fall mostly in advance of the whirlwind on the earth's surface, the lower part of the storm being retarded by friction and viscosity, while the upper ejected cold air descends.

The crystals which stud the crust of some hailstones are probably due to the deposition of regular snow-crystals, and their growth on the hailstone as it passes through a highly electric and rapidly freezing cloud. On a small scale, similar crystals of simple construction grow on heather, fern, and other plants during nights when the air is saturated, and on the verge of fog while fog is dense in valleys and on low ground. The crystals developed in fog on the same nights are more branching and feathery, and very much more so in smoky fogs near towns.*

Indentations on certain hailstones may be partly representative of irregularities on a primitive large snowflake, partly the result of eddies caused by the passage of the irregular flakes or kernels through the air.

4. The small and about equal-sized particles of an ordinary dense cloud appear to be incapable of falling in rain or snow, unless within certain limits electrically excited, and unless pervaded by drops, snow flakes, or hail kernels, proceeding from a higher level, where electricity is more potent. Thus the necessity, as a rule, for two or more layers of cloud for the precipitation of rain and snow becomes intelligible. A dense black thunder-cloud may hang for hours over a place without downfall. But as soon as the electric laboratory in a layer of cloud above the black cloud has worked, so that with increasing cold the water and ice particles are brought beyond the *status quo*, and into the attractive power of the larger crystals, precipitation begins, increasing thereby electric tension both on the surfaces of the growing crystals and at the edges of the cloud. Reactions of electric distribution then occur, and the intensity of the storm varies to some degree in relation to these disturbances.

Thus we must consider the upper cloud, and probably the upper part of it, as the real scene of origin of heavy rain and hail. The lower part of the upper cloud, and the towering lower clouds, are reservoirs which add largely to the kernel of hail or to the original droplet. We may notice in heavy showers that no rain, except perhaps a few large drops, falls from the lower cloud alone, but that the rain continues heavily from the upper cloud when the lower cloud has quite passed over.

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* See Appendix C.

Heavy and threatening clouds very frequently dissipate without any downfall. This often happens in the afternoon or evening, in summer, when the masses of clouds raised by the sun's heat begin to descend ; and sometimes it happens on the predominance of a dry northerly which was in conflict with a southerly wind.

Showers and hailstorms are thus generally due in the first place to ascending masses of vaporous air coming in contact with drier, colder, and more highly electrified air, where, with strong radiation, precipitation is determined, and to the great reduction of temperature in an ascending and expanding column of air.

5. The low temperature, the electric attraction, the rapidly proceeding condensation of vapour, and the congelation of water on ice-particles, contribute to make the nucleus harder and more compact than snow, and it therefore falls rapidly. Its temperature in the first few thousand feet of descent may be estimated at 10° to 50° F. below the freezing-point. As the hailstone falls, the temperature of the air surrounding it naturally

increases, but through the greater part of its fall is below normal. The dew-point of each successive layer encountered is above the temperature of the hailstone, so that deposition takes place with great rapidity.

6. The greater part of the cloud through which the hailstone falls consists of a dense mass of water-particles below the freezing-point, but unfrozen.* The water particles attach themselves firmly to the hailstone owing to impact, to electric attraction of the larger and more highly electrified mass, to contact with ice at a low temperature while themselves below the freezing-point, to congelation and regelation so resulting, and to cold produced by rapid partial evaporation. The latent heat set free by solidification is not sufficient to prevent the rapid growth of a hailstone passing through cold moist air. Similarly, the phenomenon of a silver thaw on the earth's surface, shows that rain slightly below the freezing-point falling on trees, glass, &c., at 31° or 32°, freezes to clear ice, and is not apparently affected by the liberation of latent heat. Moreover, observation has shown that deposition of ice on solid objects may take place to a large extent from a saturated air, without fog or cloud, when dust particles are at a minimum and wind is strong.

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* As far as I have been able to observe, the high clouds forming the upper part of a shower system do not commonly show colour-phenomena dependent on ice-crystals, or on equal water-globules.

7. The depth of dense cloud through which a hailstone falls varies very much, but in the greatest storms may be estimated at from 10,000 to 30,000 feet; but part of this depth is usually occupied by clear spaces which may be supersaturated, or in a condition to precipitate heavily on solid objects. If these spaces are below the freezing-point vapour may be condensed as a clear zone upon the hailstone. The more opaque zones are composed of particles of cloud deposited as water-globules and ice-crystals, or as very minute raindrops frozen on contact. The clear zones, and the clear base, may be often produced by drops of rain of small or moderate size overtaken by the hailstone and frozen upon it. When the clear zones are formed by deposition from clear saturated spaces between clouds, it is considered that the latent heat of condensation is partly lost to the cold air and cloud, immediately on condensation, by contact and radiation. It may be conjectured as a possibility that some part is converted into electricity.* In the case of the cold rain frozen upon the hailstone, the

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* Calculations have been made by which it appears that the heat set free, by even a little condensation and congelation, from clear saturated air, must be so great as to raise the drop or hailstone to a high temperature. But several considerations have been left out of account. A hailstone may be estimated to fall at the rate of 5000 feet a minute through the last three miles. It brings into the successive strata a temperature below their dewpoint, and the heat set free by condensation instantly passes to the cold hailstone, and to the air through which it passes, also below the freezing temperature.

latent heat of solidification is less than that produced by the conversion of water at 32° F. into ice, for the cold rain is below that temperature; this heat of solidification is partly transmitted to the cold hailstone and partly lost to the atmosphere in its rapid passage, by contact, by radiation, and by evaporation.

8. The average duration of fall of a large hailstone may be from 5 to 10 minutes from the time of formation of a small pellet. If the average volume of the hailstone be taken as an inch cube, if this represents 0·6 inch of water, and if the ground is uniformly covered with these cubes to the depth of an inch, we must assume that the equivalent depth of rainfall over the same area would have been 0·6 inch. Such a fall in 10 minutes would be a very heavy one, but not unheard of. Very heavy rainstorms or cloudbursts are probably in many cases hailstorms or snowstorms at a higher level, and the drops attain their magnitude by the precipitation of water-globules upon small ice-kernels; the ice melts in falling through the lower strata.

It does not appear that even the heaviest hailstorms exceed the presumable water-capacity of a cloud of great height and density undergoing quick renewal from surrounding vaporous strata. The area damaged by hailstorms is usually very small and their path is narrow. The hail-cloud is, in fact, a tower of moist air terminating in a region of frost; the tower moves onward, ejecting at the top the air which has ascended, and of which the vapour has been mostly condensed, and fresh warm moist air is drawn inwards and carried upwards. At the same time, in many cases, a mass of cold air descends from a great height and rushes down towards the base of the column, and often beyond it, making itself felt as a violent blast before the storm. Some hailstorms are caused by warm moist currents impinging against a mass of opposing air, and being forced upwards by it as by a steep mountain slope. Hailstorms are often caused by masses of warm and humid air not near the surface of the ground, but at an altitude of several thousand feet, bursting into upper strata which differs much from them in temperature, humidity, and electrical condition. Such hailstorms are apt to take place at night.

9. Turreted cumulus is especially indicative of hailstorm weather, and forms a very distinct phenomenon. The condition of atmosphere denoted by it may extend over very wide areas, although hailstorms only occur at a few localities within those areas.

10. The localities most affected by hailstorms are those in which temperature and humidity are often high, and above which, at heights between 15,000 and 40,000 feet, the temperature is often very low, and generally below the freezing-point when warm weather prevails on the earth's

surface; moreover, the slopes of certain mountains against which hot winds blow, places where strong up-currents are likely to be developed in a moist or very hot air, and places subject to eddies by the conformation of neighbouring mountains, are especially liable to falls of hail. Hot plains and low hills near high mountains are often more visited by hailstorms than the mountains themselves, no doubt owing to the greater heating of the low ground, and the more sudden irruption of warm into cold, or cold into warm, strata.

The hailstorms which occur in some of the hills of India and elsewhere are not due, as generally assumed, to their cooler climate, but to the easier irruption or projection of warm humid air into the upper region on sloping ground. Large hailstones cannot be melted by passing through two or three thousand feet more of warm air, and therefore it is certain that commonly they not only do not fall, but do not form, over the plains.

The equability of the ocean temperature, and the usual absence of comparatively very cold masses of air at a high level, will rarely allow the development of great hailstorms over the open sea.

11. The cold spell which often follows a hailstorm is not owing to the fall of hail, but to the descent of a block of cold air. For the cold is felt not only where the hail has fallen but in other neighbouring localities, and after slight hail-

storms or an appearance of hailclouds a similar reduction of temperature occurs.

12. The noise, which has so often drawn attention to an approaching hailstorm, and which has frequently been described as strange and peculiar, is caused partly by the rapid passage of the hailstones through the air, but chiefly by the impact of the stones on foliage and on the ground.*

13. The barometer is generally little affected by hailstorms. A fall of pressure before a hailstorm indicates an excess of vapour in the air over the locality, which is favourable to the formation of the ascending current and of heavy rain or hail. A steady barometer may signify either that diminishing pressure in the lower strata is concurrent with increasing pressure in the upper strata, or that opposite winds prevailing at different heights neutralise each other's effect upon the pressure at the earth's surface. The immediate rise which commonly takes place as a hailstorm passes off coincides with the supervention and descent of colder and drier air. With heavy falls of rain, such as 1·89 in. (see p. 20) and a rise of the barometer, there must be an in-rush of cold drier air to take the place of the vapour precipitated.

14. The shape of the disturbed area, within

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* Many years ago, on the approach of very heavy showers from the north-west, in a nearly still air, the noise of rain on the trees was audible to me at least a mile off.

which cloudy condensation takes place, sometimes, when viewed laterally, resembles a wide hourglass, or broadens at the top like an inverted pyramid, if the observer can mentally obliterate the effect of the falling rain, which in the distance resembles cloud. But in this climate well-defined storms of small area, and of the tornado type, are rare, and in general the shape of the storm is irregular, and cannot easily be defined. Observation, however, gives the impression that hail proceeds from cumulus masses heaped up to a great height, where they become obscured by or mixed with higher clouds, and that these higher clouds, in the region of cirrus and cirrostratus, spread outwards beyond the limits of the subjacent stack-cloud. The storm often seems to be derived from unstable conditions of the middle and higher levels. Observations of the clouds in the neighbourhood of local thunderstorms have led me to conclude that there is often an in-flow towards the storm centre within 5000 or 10,000 feet from the ground, while at a much greater height outflowing currents, indicated by a kind of cirrovelum, prevail.

15. The clearness of the air sometimes occurring before a hailstorm is caused by smoke and dust being carried upwards towards the cloud, and the clearness which always follows a hailstorm is caused by the descent of fresh pure air from high levels.

16. Mixture of greatly differing air-currents is not in general alone sufficient to produce heavy precipitation, as has been shown by Hann, Pernter, von Bezold, and others. But rapid condensation, and consequent production of hail and rain by other agencies, often follows from the mixture of moist warm, with cold, currents, moving from different directions.

17. The severity of a hailstorm is roughly proportional to the difference of temperature between mixing currents, the suddenness of mixture, the moisture of the warm current, and the suddenness with which it is elevated either to a great height, or into the vortex of a tornado.

APPENDICES.

A.

General Weather Conditions in Certain Hailstorms.

The following summary, derived from the daily reports of the Meteorological Office, gives a general view of the characteristic weather conditions prevailing in England about the time of the hailstorms described in the text, pp. 19–35.

May 18, 1878.—Wind southerly over England, west at entrance of Channel. Colder in Scotland, warmer in France. Thunderstorms in past night over the Channel. Hail at Scarborough and Valentia. Thunderstorms general during the day.

May 19.—Wind south-westerly. A little colder.

June 23, 1878.—Wind extremely variable. Temperature high.

June 26, 1878.—Wind easterly in France, south in England, calm in southern England. Very high temperature at 8 A.M.

Aug. 4, 1878.—Heavy thunderstorms in past night in southern England. Rain 1·7 in London, 1·0 in Scarborough. Wind north-east over North Sea, at Oxford, Scilly, Holyhead, &c. ; very light and variable or calm over southern England; west and south at Brussels, Dover, Jersey, &c.

Aug. 3, 1879.—At 8 A.M. wind easterly over greater part of the country, west over France, variable in the

Channel. Wind circulating round the Channel. Warmer on the Continent, colder in Scotland. At 2 P.M. on Aug. 2, the east wind was spreading gradually over the more northern districts. Barometer was falling in the south. Hot on the Continent, cool in England.

June 15, 1888.—Wind east over Britain, very variable over France. Temperature rising.

Aug. 24, 1889.—Wind west, west-north-west, south-west. London south-south-west, Hurst Castle, west-north-west.

Aug. 29, 1889.—Variable airs.

Sept. 21, 1889.—Wind uniformly north-west over the British Isles and France. Lightning last night at several places. Temperature low. Wind south-east at Haslemere.

Aug. 4, 1891.—Light or moderate, north-east over Norway, Scotland, and northern England; north to north-west on west coasts, west in west France; south-west over south-east England, Germany, and Netherlands.

April 26, 1892.—North-west winds, west in Channel and northern France. Temperature lower.

May 25, 1892.—Wind south and variable.

If the above instances be taken as typical, it appears that the most favourable conditions for the production of hailstorms in Great Britain are as follows, in the order given:—

1. Variable airs, and small cyclonic areas, or barometric troughs, having easterly winds on the north and westerly winds on the south side.

2. Variable westerly and southerly winds, with high temperature.

3. Wind generally from one quarter over the whole country, with a few local exceptions in small areas, affected by calms or opposing currents.

The variable airs most favourable to the production of thunder and hailstorms are found not only in an horizontal but also in a vertical section. It is remarkable that one of the very greatest recorded hailstorms in England took place at night, with a north-easterly wind in the lower atmosphere, and a south-westerly or southerly current in the upper region. It would seem as if the cooler wind had raised the warm stream above it to a higher level, where great cold produced copious precipitation. There was incessant lightning between the layers of cloud.

B.

COLD PRODUCED BY RADIATION FROM THE UPPER STRATA OF CLOUDS AND FOG.

The effects of radiation from the particles of water which constitute cloud and fog has, I think, never been duly estimated.

I find in the Quarterly Journal of Meteorology for 1842 an article by a member of the Meteorological Society, on 'Fog and Frost at Great Malvern,' which gives remarkable instances of differences in temperature between the upper stratum of fog and the clear air above it. On December 24, 1835, the air on the hill was clear and fine; at St. Ann's Well the temperature was 30°, while 200 feet lower, in the upper stratum of fog, the temperature was only 20°. On December 26, at 11 A.M., a little way up the hill there was clear sunshine, and the temperature was 32°; at the shrubbery, a little higher, it was 35°; at 200 yards distance down the road, in the upper stratum of fog, it was 18°.

I have myself observed similar differences, both at Malvern and elsewhere. In February, 1891, the plain below Malvern was covered with dense fog, which in the morning extended to the topmost houses of the town. A few yards higher and on the hills the air was warm with bright sunshine, while in the fog and especially on the plain all objects were coated with thick rime. Only after some hours of sunshine was the fog dissipated. Now it appears to me indubitable that, unless the upper stratum of fog radiated actively into space, the warmth of the sun and the contiguity of the warm superjacent air would very soon have dissolved the upper layers of fog. It is only when the sun is strong enough to exceed the heat lost in the particles by radiation that the fog becomes vaporised and rises through the air above it.

The condition of the air up to a great height in an anti-cyclone is favourable to the rapid loss of heat by a fog stratum near the earth, for it is much drier and more diathermanous than usual. But no loss of heat by fog near the surface of the earth can approach in rapidity the loss by the upper layers of cloud at such altitudes as those attained by the high clouds from which precipitation takes place in heavy thunderstorms and showers. The humidity of the air above them is very low, the air thin, and there are no layers of vapour or thin cloud to intercept the heat rays given out from the upper cloud of the shower system. It seems not unlikely that such a temperature as was recently recorded in one of the exploring balloons at about 45,000 feet, viz. – 51° C., may be frequently reached by cirrifying cumulus or by the cirro-velum of thunderstorms. The greatest cold would be likely to occur not immediately over the ascending column, where the heat of condensation would add largely to the warmth of the air at the top where it spreads and flows over laterally, but rather at some little distance from the capital of the column, where the outward-flowing currents with their watery contents would come in contact with the cold air of the high level, and would become sufficiently extended to present a more freely-radiating surface to the sky. Crystals there formed would be highly electric, and would, in falling, quickly increase their bulk owing both to their low temperature and to electric attraction. Hail would reach the earth's surface from the edge, front, or rear of the darkest cloud in the storm.

C.

DUST-PARTICLES AND THE FORM OF ICE-CRYSTALS.

Before Christmas, 1891, a dense fog with hard frost overspread a large part of the country, and for several days remained undissipated over the neighbourhood of London. A certain amount of mist or fog was noticed in the valleys of the extreme south-western part of Surrey early in the mornings, but the hills were clear. I found that the ice-needles formed on vegetation on the moors, 700 and 800 feet above the sea, were of simple construction, chiefly hexagonal needles. On low ground, where fog had been, the needles bore a few branching crystals. At Richmond the crystals were very different, being highly feathery and fern-like, with numerous smaller crystals branching from the stem. The foggy air had been so thick with London smoke for some days, that when the rime melted the resulting water was darkly discoloured. It appears probable that the simplicity or complex character of snow-flakes may similarly depend largely on the number of dust particles in the air where they have their origin.

D.

TYPES OF HAILSTORMS.

The weather conditions which give rise to hailstorms, and the disturbances which result in falls of large hail, may conveniently be divided into the following types.

1. Moist warm air impinges against steep mountain sides, and in its ascent the contained vapour becomes condensed by cooling due to expansion; this generates a large amount of sensible heat, which raises the saturated stream of air to a still greater height, where cooling by expansion and radiation further increase precipitation. The fall of rain or hail may extend many miles to wind-

ward of the mountain range, owing both to the raising of the air at some height above the ground by the pressure of the obstacle in front of it, and to the outflow and backflow of cooled air at a great height, which has reached a level not subject to the prevailing wind of the lower strata.

Examples: Western Ghâts and neighbouring country parallel to them westward, mountains of Jamaica, of Natal, of Queensland, Andes.

2. During great heat, atmospheric equilibrium is upset, and over various localities warm moist air breaks into an upper cold stratum, from which, in consequence, corresponding masses descend. The conditions favourable to these exchanges are, obviously, calms, and variable or contending air-currents, excess of temperature and vapour in lower, and deficiency in upper strata, inland situations at some moderate distance to the southward of great mountain ranges, and in a less degree, absence of thick vegetation. Northern India, North Italy, Georgia, and the country south of the Caucasus are favourably situated for the development of such storms. Good examples of the occurrence of storms due to the causes mentioned sometimes occur in England. Of quite recent hailstorms the most notable is that which broke over Richmond, in Yorkshire, and other places, on July 8, 1893.

This, like so many other hailstorms, took place in the midst of contending easterly and westerly winds, and during atmospheric conditions in which great heat and differences of temperature were the chief characteristics.

The hailstorms of May 19, 1888, and June 2 (afternoon), 1889, and June 6 and 7, 1889, occurred in somewhat similar conditions.*

On May 19, 1888, at Glasgow, rain fell in torrents in the afternoon, then dense showers of large hailstones, alternating with blinding sheets of water. The commotion in the clouds was appalling, the lightning and thunder were incessant. Enormous flashes passed from cloud to cloud, and from cloud to earth.

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* 'The Thunderstorms of May 18 and 19, 1888'; 'The Thunderstorms of June 2, 6, and 7, 1889,' by W. Marriott. Quart. Journal of the Royal Met. Soc., Oct. 1888 and Oct. 1889.

On June 2, 1889, there were hailstorms in the West Midlands, in north-west England, and in south Scotland, between 1 and 5 P.M. The hail was very large. In the Black Country it was 1 inch in diameter and 4½ inches in circumference; at Garstang, one ice-block was 7 inches in circumference, many hailstones were 5 inches. They were mostly round like glass marbles covered with large crystals of ice, looking like sugar-candy. At Liverpool, many had 4, 5, or 6 concentric layers, alternately clear and snow-white. On June 6, a thunderstorm, with hail of tremendous size, raged for several hours over west Norfolk from 7.30 P.M. At Bagthorpe the hail was 4 or 5 inches round, and weighed over 1 oz.; at Castleacre some hailstones were 8 or 9 inches round; at Sporle one was 8 inches; at Swaffham they were like hen's eggs, with centres of clear hard ice. The storm began in London a little before 9 P.M., and was remarkable for a continuous and brilliant display of lightning. 1244 flashes were counted from 9.10 to 11.10 P.M. On June 7, between 2 and 3 A.M., at Westgate, and over east Kent, there was a storm with large hail. The flashes were more than 131 in the minute. Between noon and 3 P.M. there were severe thunderstorms over the southern counties from Kent to Dorset and Somerset. At Tunbridge Wells one hailstone is said to have weighed half a pound.

In France, such storms are apt to be more severe than in England. On the 7th of May, 1865, the north-east of France was visited by a violent hailstorm after a long period of dry, warm weather, and several days of scorching heat. At 7 A.M. on the 7th, the air freshened, and the barometer rose. A wind from north-east chased light clouds before it; higher up, a south-west wind prevailed, bearing slowly before it woolly-looking clouds, which grew denser towards noon. The air was calm from noon to 3 P.M., when heavy clouds, piled on each other, arose from the south-west, and thunder was heard. Above the lower cloud, from which lightning darted continually, were many layers of sombre-tinted clouds, forming a broad base to the lower cloud, resembling an inverted pyramid. Hail as large as pigeons' eggs fell at Câtelet. Next morning a mass of hailstones was found more than a quarter of a mile in length, 22 yards in breadth, and, in places, 16 feet in height. A mill was levelled with the ground, and large trees torn up by the roots. It seems clear from this description that the hailstorm must have been accompanied by a hurricane.

3. Some storms pass with great rapidity across the country, and affect only such localities as lie within a narrow track. Of this character were the famous hailstorms of July 13, 1788, in France, and the storms of May 18, 1888, and June 2 (morning), 1889, in England.*

The double storm of 1788 passed across France and Belgium at an average rate of about 38 miles an hour. The thunderstorm of May 18, 1888, passed across England from near Christchurch, Hants (8.15 P.M.), to Edinburgh (4 A.M.), at the rate of 50 miles an hour. No hail is recorded in this storm. The hailstorm of June 2, 1889, passed from Wiltshire (3 A.M.) to Edinburgh (10.44 A.M.), at 50 miles an hour. Large hailstones fell at Droitwich, Wollaston, Bolton, and Meltham. About 11 A.M. on the same morning, large hail fell along the Tweed, some stones being 1⅝ inches in diameter.

These storms may be caused by the irruption, locally, of a cool wind into very warm air at a middle or great height, and by the descent of this cool wind, say from a direction at right angles, into the surface wind, producing a rapid eddy moving in a resultant direction. The disturbance so produced, with excessive condensation and precipitation of vapour borne aloft and mixed with cold air, tends to increase greatly the force of the whirlwind, which acts as a vent for the overheated air of the plain into the upper region. Such a storm may either move along bodily, as an eddy moves down a river, or it may be propagated along the line of successive contact of the cool with the warm current. In the latter case the storm appears to advance with great rapidity, though only the conditions are really propagated at the apparent rate. When, however, the invading cool air impinges simultaneously against a mass of warm air moving from another direction, storms break out simultaneously across a great extent of country, and partake of the stationary character as described under type No. 2.

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* Quarterly Journal of the Royal Met. Soc., Oct. 1888 and Oct. 1889. W. Marriott. F.R. Met. Soc.

Sometimes very considerable hailshowers occur during the prevalence of a steady lower wind, say from west, over the country. These seem to be due to small local disturbances from two causes, the local ascent of comparatively warm air to a height, and the existence of specially cold masses of air of small extent over parts of the prevailing wind. Very often the condensation of vapour at a great height, which precedes a hailstorm, is brought about by a current from a more northerly point at a great altitude, and eddies or heavings-up are produced about the place of invasion. In fact, that occurs at a height in summer which often occurs at lower levels in winter, a gust of north-west wind invading a south or south-west wind, and producing rapid and heavy precipitation, snow, or rain. When this takes place at the lower cirrus altitudes in summer, heavy snow or graupel is produced, which, in falling through thick freezing clouds, thousands of feet in thickness, may grow into heavy hail.

E.

NOTES ON RECENT THUNDERSTORMS AND HAILSTORMS.

June 26, 1893.—During the day the wind was pretty steady from about south-west, and the weather continued fine till about 5 P.M., when some heavy drops fell from a high pale cloud moving from south-west. About 5.30 P.M. a moderately dark and rather narrow cloud was seen approaching from south-west. It gradually increased in depth and bulk, and instead of continuing to advance north-eastwards, sheared off along the Sussex Weald eastward, and soon began to develop considerable rainfall, showing perpendicular dashes. It grew eastwards and remained stationary for the next two hours or more, very black and heavy, with a great deal of forked lightning and thunder. No rain fell at Haslemere, and the nearest part of the storm was three miles to the southward. While the dark low cloud and rain remained at that distance, the upper cloud grew outwards from above them and extended overhead as a dusky cirrus and cirrostratus. Much below this cirrus, but still at apparently the full height of ordinary detached summer cumulus, little detached masses of cloud kept pouring in steadily towards the storm from north-north-west, and for a short time the wind at the earth's surface changed to north-west, drawing back to south-west as the storm ceased. Next day I found that at Fernhurst and Midhurst a heavy thunderstorm had occurred, and that a tree had been struck by lightning.

On examining the weather chart for June 26, 8 A.M., the cause of this disturbance is seen to be related to a barometric irregularity then situated over the mouth of the English Channel. Over southern England and southern Ireland the wind was south-east and south; at Scilly, east; over north-western France, south-west and west-south-west; at Prawle Point, east; at Jersey, west-south-west; at Hurst Castle, south. These winds were mostly moderate or fresh. Thus a circulation of winds was prevalent within an area of about one hundred miles. The thunderstorm over West Sussex marked the opposition of winds, resulting in calm there about 6 P.M. on June 26, although the south-westerly breeze in the neighbourhood showed little variation during the day. The air to the north of the storm at a middle height moved towards the disturbance, and at the upper level apparently away from it. To the south of the storm, if observations had been taken, it is probable that the middle air would have been found to be similarly moving northwards towards the disturbance, and the upper air to be moving away from it.

July 8, 1893.—This morning, at Haslemere, there was a good deal of cirro-stratus and turreted cirro-cumulus moving from south and south-south-east, and this continued remarkable during the day, with cirro-cumulus of rather a dense and solid aspect. These clouds moved steadily northwards all day, and were very abundant. Lower clouds of a cumulus-scud type, and cumulus, passed from south-south-west. Wind about south. In the evening the clouds darkened, and about 9.30 P.M. there was a shower. The clouds were of a noteworthy character, but without precipitation.*

The following notes are derived from an examination of the weather chart for July 8. At 8 A.M. pressure was high over Scandinavia, Denmark, Germany, and Spain; low (29·6) in a depression reaching the west of Ireland. Gradients were slight, barometer falling in England. Temperature exceedingly high at places in England (80° in London, 79° at Cambridge) and rather low in the south of Scotland, &c. (55° at Leith, 60° at Shields). Wind generally easterly over the north of England, in

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* MS. Notes, R. Russell.

Scotland, and in Ireland, south-easterly over southern England, southerly and south-westerly on the south coast, and at Brest and Lorient. Weather generally fine and bright, but a thunderstorm had occurred at Ardrossan, thunder at Roche's Point, Scilly, Donaghadee, and Hurst Castle (July 7, evening).

At 2 P.M. on July 8 the barometer had fallen, wind was still easterly in Scotland and the north of England, but south-westerly in southern England, south in London and at the north Foreland, south-east at Yarmouth. The temperature rose, in certain places in England, to 96° as at Elsing, Norfolk, and to between 85° and 92° in some other parts. In the afternoon very heavy thunderstorms and tremendous hailstorms, accompanied in some cases by whirlwinds, took place in the north of England. Rainfall 1·4 at Liverpool, 1·2 at Shields. Temperature fell very greatly at many places before the evening.

At 6 P.M. on July 8 there was thunder at North Shields, Spurn Head, Dungeness, North Foreland, Cambridge, and Cape Grisnez. Wind was north-east at Shields, south-west at Loughborough.

At 8 A.M. on July 9 the barometer had further fallen, and was lowest over the north of St. George's Channel, the wind generally being southerly and westerly over the south and east, and easterly over the north of Great Britain. Temperature was below 60° at many places, irrespective of wind direction.

The great storms of July 8 in the north of England appear to have been owing both to the approaching cyclonic depression and to the exceedingly high temperatures of the morning. The easterly wind blowing from the North Sea encountered masses of air moving from the west and south and containing a large amount of vapour, sufficient to be condensed as cloud at a great height. The cooler air drawn in upon the north of England by the heat over the land would meet warm currents from south and west, impelled by the barometric pressure towards the east of the depression approaching from the west. These opposing influences reached their maximum in the afternoon, and resulted in heavy precipitation, thunderstorms, hailstorms, and whirlwinds. Temperature fell much in the afternoon; thus at Cambridge it was only 71° at 2 P.M., after an 8 A.M. record of 79°. At Shields the temperature fell below 60°. At Liverpool temperature at 8 A.M. on the 8th was 73°, at 8 A.M. on the 9th, 58°.

Aug. 4, 1893.—In the evening of Aug. 3 there was much fine towering cumulus, producing a remarkable effect, and continuing to reflect a greyish-green sunset light during the late twilight. The morning of Aug. 4 was fair, with cumulus having an appearance indicating a probable development of showers, but these cleared off and the day became fine till 1 P.M., when the cumulus suddenly increased and a dark cloud passed over. The sky was again pretty clear till about 4.30 P.M., when a very dark cloud with ragged scud cumulus under it, approached and passed over without rain, or with only a few drops. The wind slackened, however, and a gentle shower ensued, with a good deal of thunder and lightning in a part of the cloud. Wind south-west. Fine evening, with grand cumulus towering in the east.*

The weather chart for 8 A.M. showed a nearly regular decrease of pressure from mid and southern Europe, the north of Ireland, and Scotland, where the barometer was 29·40. Wind was south-westerly from the north of France to the north of Great Britain; temperature fairly uniform between 60° and 70° in the south, and a little under 60° in the north. In London, however, 73° was recorded at 8 A.M.

At 2 and 3 P.M. there were heavy thunderstorms in London and in other parts of the country. About the same time as in London a very severe thunderstorm occurred in north Hampshire. A heavy thunderstorm, with hailstones of enormous size, visited Driffield and other towns in Yorkshire.

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* MS. Notes.

Aug. 8, 1893.—The day was fine and cloudless with the exception of a large quantity of ravelled cirrus, with many twists and curls, some portions having long streamers hanging apparently some thousands of feet downwards as ice-particles and gradually dissolving in the warmer air below them. A strong east wind blew during the day, but the cirrus moved from south-west or west-south-west.*

Aug. 9, 1893.—At 8 A.M. wind was easterly from the north of France to the north of Scotland, south at Brest and Scilly; pressure high in Scandinavia and Germany, comparatively low (29·8) off the south-west of Ireland. Temperature high in England and Ireland.

At 6 P.M. wind was easterly over the south-east and north of England and in Holland, south-easterly in Scotland, south-south-east at Scilly, calm at Prawle Point, south-south-west at Brest, west-north-west at Jersey, east-south-east at Hurst Castle, west at Lorient. The lowest pressure was over Ireland. The barometer was falling fitfully except in the far north. A maximum temperature of 86° was reported in London, 84° at Jersey, 83° at Holyhead, 80° at York. At 7.40 P.M. there was a dead calm at Lundy Island.

At Haslemere, just after sunset, there was a remarkable range of towering cumulus in a low bank along the south-west and west horizon, like a great city with battlements and martello towers on its walls. There were no clouds elsewhere. Wind was still east, but falling light. The upper current had continued from south-west, but during the day there was all the appearance of settled slightly hazy weather with east wind. About 8.30 P.M. and later during the whole evening, lightning was very bright in the west, and the sky was clear except for the distant low bank in the west.†

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* MS. Notes.

† Ibid.

The heat of Aug. 9 was generally described as very great. At 4 P.M. on this day large hailstones fell at Preston, with pieces of ice two inches in circumference. Storms also occurred in Ireland, at Helensburgh (5 P.M.), at Blackburn, and at Devizes (in the evening). In London quite early in the evening, faint lightning was occasionally visible in the west, and after 9 o'clock the flashes became of much more frequent occurrence, while between 10 P.M. and midnight there was scarcely a second between the successive flashes (*Daily News*, Aug. 11). It would appear from this account that the lightning between 8 and 9 P.M. in London was the reflection of flashes in Wiltshire.

Aug. 10, 1893.—At Haslemere a short sharp thunder-shower fell about 1.35 A.M., which was heavy at Godalming. The wind was still east, but gentle. A thunderstorm occurred in London about 1.30 A.M.; in Anglesey, early in the morning with south-south-west wind; at Ramsgate a heavy shower early; about the same time a very heavy thunderstorm (four hours), with little rain, at Deal, Folkestone, and the neighbourhood; thunderstorms at Great Yarmouth, Lynn, Nuneaton (2 A.M.), Melton Mowbray, Windsor; in Oxfordshire, Cambridgeshire, north Hertfordshire, south Bedfordshire, south Lincolnshire; in north Leicestershire the storm was severe between 1 and 3 A.M., in Essex about 3 A.M.; at Birmingham 71 flashes a minute were counted in the early morning. In many places the lightning and thunder are described as terrific (see *Daily Chronicle*, Aug. 11), and in Hertfordshire and Bedfordshire as lasting about six hours. Near Hatfield the hailstones were of extraordinary size.

On the morning of Aug. 10, at Ramsgate, the wind is described as "a fresh little breeze from east-south-east" which veered to "south-west by west in the evening." At Cambridge it was east, with thunder at 8 A.M. The calm and change of wind thus appears to have taken about 20 hours to cross from Lundy Island to Ramsgate.

At Torquay, on Aug. 10, a fresh west-south-west breeze prevailed during the afternoon. In the south and west of England wind was south and west at 8 A.M.

At 9.30 A.M. on Aug. 10 temperature had been only 58° at Ostend, 54° at Brussels, but 67° at Calais, and 72° at Boulogne. At 8 A.M. 67° in Ireland and the west of England.

In the evening (Aug. 10), after 8 P.M., lightning was seen in the east and south-east, and occasionally in the south. The sky was nearly clear, wind fresh from west since the morning. The sheet lightning seems to have been reflections of lightning in the Straits of Dover, or off the North Foreland, and in the north of France.

F.

STORMS OF HAIL AND RAIN PRODUCED BY MIXTURE OF WINDS.

Some of the most distinguished German meteorologists—Von Bezold, Hann, Pernter, Wettstein, and others—have as a result of their researches and calculations, concluded that the rainfall produced by the mixture of differing masses of air can only be very small, if any.* Wettstein, for instance, considered that mechanical mixture would never alone cause condensation and rain; Hann that it could only cause slight precipitation; and Von Bezold has shown how small the amounts of precipitation really are by the process of air mixture alone.† Von Bezold finds, however, that when warm saturated air is mixed with cooler, the cooler air may be very dry and yet condensation may take place; that when saturated warm air is mixed with unsaturated cool air, condensation occurs much more easily than when saturated cool air is mixed with unsaturated warm air; that a wedge of saturated warm air penetrating into a mass of cool air will be accompanied by a stronger condensation than in the case of a wedge of saturated cold air entering into a mass of warm air; that condensation takes place more rapidly when a wedge of cool moist air enters a large mass of warm air than when a wedge of warm moist air is blown into a mass of cool air; and that, in general, condensation of water vapour is brought about by contact with colder bodies and radiation, by adiabatic expansion, and by mixture of masses of air having different temperatures, in the order given. He shows that, in an instance where two masses of saturated air are mixed, having temperatures of 0° C., and 20° C., only 0·75 grammes of rain would result per kilogramme of the mixture, an amount which would be obtained from an ascent of the warm air of only 310 metres, or a cooling of the warm air down to 19°·2, only 0°·8 C. Mr. Waldo observes that it is probably only in very extreme cases that a difference in temperature can exist in two adjacent masses of air, sufficient to produce rainfall at all when they are simply mixed together.

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* See 'Modern Meteorology,' Frank Waldo, 1893.

† See 'Zur Thermodynamik der Atmosphäre,' Dritte Mittheilung. Von W. von Bezold. Sitzungsberichte der K. Preussischen Akad. d. Wissenschaften, Berlin, 1890.

Now these results appear to me to be in opposition to actual experience of the development of rain, snow, and hail, under the broad conditions of nature. Rain commonly falls steadily and not heavily in the front part of a cyclone from the west in England, resulting probably in part from the ascent of the lower air and in part from contact with cooler upper currents. If, however, a sudden change of wind to west or north-west occurs, heavy rain or snow falls, and then the sky clears under the influence of the drier current extending throughout. This heavy shower seems to result from the sudden mixture of the two differing winds, when the more northerly and colder current descends upon the lower air. When the movements of the clouds concerned in heavy showers are watched, the development of the showers in many cases seems to depend on the mixture of winds from slightly different directions. The authors above quoted allow that a great deal of cloud formation takes place by mixture. Now, when once the vapour contained in the air-masses is condensed as cloud, several considerations appear to justify the inference that the bye-results, as it were, of mixture may contribute to heavy downfalls. Radiation is active in the upper cloud, electricity strongly developed, and cold electrified particles of rain, snow, or hail, fall through the dense cloud produced by mixture as well as by elevation. So far as my observations go, a great deal depends on the suddenness of the mixture as well as on temperature differences as regards the amount of precipitation. In sudden mixture condensation is irregular; particles of water or ice greatly differing in size are quickly formed, electricity is strong, and often a downblast of cold air does not become normally warmed by compression owing to the barometric pressure being relatively lower at the low than at the high level. The quick rise of the barometer in the midst of a squall or shower of this kind indicates the denser or drier character of the supervening current. In the case of hailstorms, further considerations, which have been brought forward in the concluding chapters of this volume, suggest that theory may have omitted to take into account some potent influences which are concerned in the production of heavy falls of rain and hail, and that, with the aid of these influences, a mixture of winds is actually in many cases an important cause of precipitation.

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Photograph of Hailstones (actual size), taken after the Terrific Thunderstorm at Richmond, Yorkshire, on the 8th of July, 1893.

By H. J. Metcalfe, Photograher, High Row, Richmond, Yorks.

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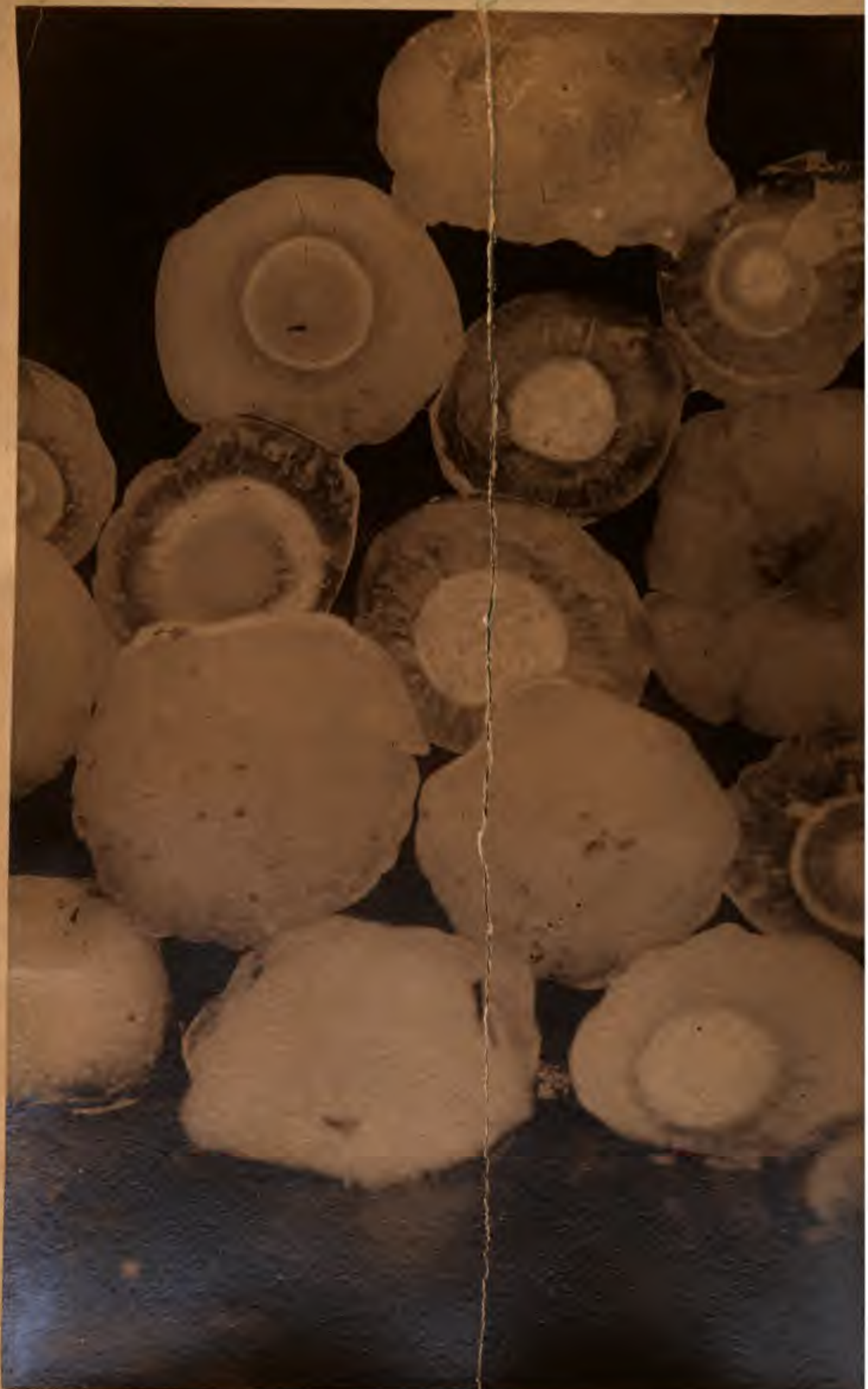

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